# A STUDY OF REMOVAL OF PRECIPITATED IRON IN WATER USING FILTRATION

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CIVIL ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
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by

Mohd Afiq Bin Harun

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil Engineering)

JANUARY 2009

Universiti Teknologi PETRONAS

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Perak Darul Ridzuan

# CERTIFICATION OF APPROVAL

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Approved:

Dr Amirhossein Malakahmad
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2009

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Afiq Bin Harun

# ABSTRACT

A research were made to study the feasibility using sand in filtration pilot plant and also evaluate its performance to remove precipitate iron from water by using filtration. The pilot plant consists of a column packed with filter media, a transfer pump, sump tank, a rotameter, a bank of manometer tubes and various valves for flow control and sampling point. Cylindrical column are made of clear acrylic. Filtration column is 250mm in diameter and 3m in height. Thickness of the column wall is 5mm. Fine sand media (350 to 800 micron) are used as the media of the filtration column. Equipment such as vials, stop watch and turbidity meter also are included. Overall dimension, height is 4.15m, 1.22m width and 1.22m depth. Evaluation on the best efficiency of filtration pilot plant was made by observing water quality produce by the filtration pilot plant. Influent and effluent qualities including turbidity, colour, and iron concentration were observed. In total six experiments were perform. The iron concentrations of the experiments were 21.2 mg/L, 11.7 mg/L, 5.75 mg/L, 3.60 mg/L, 3.55 mg/L, 2.07 mg/L. Preliminary experiment shows that higher flowrate of filtration give better percentage removal of turbidity, colour, and iron concentration. Backwashing time for 11.7 mg/L and 21.2 of iron concentration are 32 minute and 22 minute respectively. Percentage iron removal for both concentrations is 99%. The filtration pilot plant capable of to filter precipitate iron more than 21.2 mg/L since the water quality still do not meet Standard B Environmental Quality Act 1974 (5 mg/L). Concentration of iron lower than 2.02 mg/L just need the height of sampling point 2 which is 0.3m to achieve Standard A Environmental Quality Act 1974.

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# CHAPTER 1
# INTRODUCTION

## 1.0 Introduction

## 1.1Background of study

Iron is one of the most abundant metals of the earth crust. Presence of iron occurs naturally in water in soluble form as the ferrous ion (bivalent iron in dissolved form Fe (II) or Fe $(OH)_2$ or in the complexes form like the ferric ion (trivalent iron: Fe (III) met in the precipitin Fe $(OH)_3$ or in the bacterial form. Source of iron in water are industrial origin, mining, steel industry, metal corrosion, chemical reaction, etc. ( Ghosh *et al.*, 2007)

Cho, (2005) mention that in the drinking water and water supplies, iron causes problem such as giving reddish colour and odour. Iron also consume chlorine in the disinfection process and promote biofouling and microbiological induced corrosion in water system. ( Pacini *et al.*, 2005)

Iron is applied worldwide for commercial purposes, and is produced in amounts of 500 million tons annually. Some 300 million tons are recycled. The main reason is that iron is applicable in more areas than possibly any other metal. Alloys decrease corrosives of the metal. Steel producers add various amounts of carbon. Iron alloys are eventually processed to containers, cars, laundry machines, bridges, buildings, and even small springs. Iron compounds are applied as pigments in glass and email production, or are processed to pharmaceutics, chemicals, iron fertilizers, or pesticides. These are also applied in wood impregnation and photography.

Iron does not clearly alter in pure water or in dry air, but when both water and oxygen are present (moist air), iron corrodes. Its silvery colour changes to a reddish-brown, because hydrated oxides are formed. Dissolved electrolytes accelerate the reaction mechanism, which is as follows:

$$4\,Fe + 3\,O_2 + 6\,H_2O \longrightarrow 4\,Fe^{3+} + 12\,OH^- \longrightarrow 4\,Fe(OH)_3 \text{ or } 4\,FeO(OH) + 4\,H_2O$$

Usually the oxide layer does not protect iron from further corrosion, but is removed so more metal oxides can be formed. Electrolytes are mostly iron (II) sulphate, which forms during corrosion by atmospheric $SO_2$. In sea regions atmospheric salt particles may play an important role in this process. Iron (II) hydroxide often precipitates in natural waters. Elementary iron dissolves in water under normal conditions. Naturally occurring iron oxide, iron hydroxide, iron carbide and iron penta carbonyl are water insoluble.

Other iron compounds may be more water soluble than the examples mentioned above. Iron carbonate has a water solubility of 60 mg/L, iron sulphide of 6 mg/L, and iron vitriol even of 295 g/L. Usually there is a difference between water soluble $Fe^{2+}$ compounds and generally water insoluble $Fe^{3+}$ compounds. The latter are only water soluble in strongly acidic solutions, but water solubility increases when these are reduced to $Fe^{2+}$ under certain conditions. The type of iron that will be treated using filtration pilot plant in this research is insoluble compound which is $Fe^{3+}$ compound.

Environmental issues rose when disposal of industrial pollutant are almost so toxic that wastewater has to be treated before its reuse or disposal in water bodies.( Tayim and Al-Yazouri, 2005) In treating the wastewater, maximum allowed limits for contaminants are enforced in many developing countries including Malaysia. According to the environmental quality act 1974, parameter limits of effluent such as iron for standard A and B is 1mg/L and 5mg/L. Table 1.1 shows the parameters detail regarding environmental quality act 1974.

Table 1.1: Environmental Quality Act 1974 (Environmental Quality (Sewerage And Industrial Effluents) Regulation 1978

[Regulation 8 (1), 8 (2), 8 (3)]

Parameter Limits Of Effluent Of Standards A And B

| Parameter | Unit | Standard | |
|---|---|---|---|
| | | A | B |
| | | | |
| Temperature | C | 40 | 40 |
| pH Value | | 6.0 - 9.0 | 5.5 - 9.0 |
| BODs at 20°C | mg/L | 20 | 50 |
| COD | mg/L | 50 | 100 |
| Suspended Solids | mg/L | 50 | 100 |
| Mercury | mg/L | 0.005 | 0.005 |
| Cadmium | mg/L | 0.01 | 0.02 |
| Chromium, Hexavaient | mg/L | 0.05 | 0.05 |
| Arsenic | mg/L | 0.05 | 0.10 |
| Cyanide | mg/L | 0.05 | 0.10 |
| Lead | mg/L | 0.10 | 0.5 |
| Chromium, Trivalent | mg/L | 0.20 | 1.0 |
| Copper | mg/L | 0.20 | 1.0 |
| Manganese | mg/L | 0.20 | 1.0 |
| Nickel | mg/L | 0.20 | 1.0 |
| Tin | mg/L | 0.20 | 1.0 |
| Zinc | mg/L | 1.0 | 1.0 |
| Borom | mg/L | 1.0 | 4.0 |
| Iron (Fe) | mg/L | 1.0 | 5.0 |
| Phenol | mg/L | 0.001 | 1.0 |
| Free Chlorine | mg/L | 1.0 | 2.0 |
| Sulphide | mg/L | 0.50 | 0.50 |
| Oil and Grease | mg/L | Not Detectable | 10.0 |

Treating wastewater is becoming an increasingly important aspect of process operation, particularly with the more strict environmental regulations. Fresh water cost and availability, environmental concern, wastewater disposal cost and climate influence has caused many companies to recycle their wastewater. Appropriates selection in wastewater recycling process is rather difficult with wide variety of traditional process available and new, less established technology evolved. ( Sheikholeslami and Bright, 2002 ).

It is clearly shows that iron wastewater for discharging and raw water purpose must not exceed more than 5 mg/L. Treating iron wastewater using filtration method will help us to achieve that standard. Basically filtration is the removal of particles by sieving through a granular media. ( Davis and Mastern, 2009 ) Filtration often acts as a polishing step to remove small flocs or precipitant particle not removed in setting of coagulated. ( Peavy *et al.*, 1985 ).

In this study, filtration will be used as the method to remove iron wastewater. A pilot plant will be constructed and iron wastewater will be treated using filtration technique. The best efficiency of the filtration pilot plant also will be observed.

**1.2 Problem Statement**

Iron in water supplies cause problems such as giving reddish colour and odour. These metals consume chlorine in the disinfection process and induced corrosion in water networks. Iron precipitates also are difficult to settle and filter. This paper will describe research undertaken to study the feasibility using sand in filtration pilot plant and also evaluate its performance to remove precipitate iron.

In environmental engineering courses, labs are being conduct every semester to demonstrate several theories such as sedimentation tank, filtration operation and so on. The batch settling filtration column has been design for demonstration of granular filtration. Backwashing is done to clean the media and the overall filtration column. However, every semester, backwashing is done by trial and error method. Exact time for

backwashing is not known and as a result backwashing is done only when the system is clog. A study will be conducted to know the efficiency of the filtration column by studying the water quality of the sand filter. Water that had been used in this filtration experiment contained precipitated iron. Series of concentration from 2mg/L to 20mg/L will be used to observe the removal efficiency of the filtration pilot plant. In conjunction with that, allocation of backwashing time will be done by observing water quality from the filtration pilot plant. Three tests will be performed to measure water quality of the system. The tests are turbidity, colour and iron concentration. The results then will be compared with the parameter limit Standard A and B Environmental Quality Act 1974.

### 1.3 Objectives

Aims of this research are:

a) To evaluate the best efficiency of filtration pilot plant by locating backwashing time and removal efficiency of iron, colour and turbidity.

b) To compare performance of filtration pilot plant in Universiti Teknologi Petronas with Standard A and Standard B Environmental Quality Act 1974

### 1.4 Scope of study

This study will focus on evaluating the best efficiency for filtration column. Pollution level of the influent and water quality of the effluent will be study to know the performance of filtration column. Quality of the influent and effluent such as turbidity, colour, pH and will be observed. The best efficiency of the filtration column will be suggested base on system efficiency. Since water contained precipitated iron is used in the filtration process, this research also will cover the removal efficiency of water contain precipitate iron using filtration process. Different concentration of precipitate iron will be tested to the filtration system. Backwashing time will be determined by observing the removal efficiency of the filtration system base on the water quality test. Removal of iron will be compared to Standard A and Standard B Environmental Quality Act 1974.

# CHAPTER 2
# LITERATURE REVIEW

## 2.0 Literature review

## 2.1 Introduction

Currently, suitable water supply for people and industry has become more difficult to find. Rapid development of different branches of industry and agriculture contribute to fast increase of the environment degradation and simultaneously to a decrease of drinking water reservoirs. Continuous increase of pollutants concentrations is observed in natural reservoirs for a water supply system. The main sources of contaminations are industrial or urban wastewater, wastes, sewage, sludge, pesticides, artificial fertilizers or end-products of self-purification of water. Their chemical compositions are mainly influenced by industrial organic compounds content. The contaminations affect properties of water, are toxic or even carcinogenic for human beings ( Choo *et al.*, 1999 ).

The advanced treatment of wastewater is necessary because of the changes in global climate and population. Drought, population increase and changing lifestyles have caused an increasing demand for fresh water resources. In some parts of the world this has already led to water shortages, but in relatively few cases the effluent of wastewater treatment plants (WWTP effluent) is used as a water resource. ( Roordaa, J and van der Graaf, 2004 )

Iron at low concentration at very low concentration is highly objectionable in water supplies for domestic or industrial use. It can cause staining of bathroom fixtures, impart a brownish colour to the laundered clothing and can affect the waster taste (

Hammer and Jr. Hammer, 2004 ). According to Tayim & Al-Yazouri (2005) the concentration range of heavy metals in untreated wastewater for iron is between of 0.12-24.32 mg/L

**2.2 Filtration**

Filtration is often used in modern water treatment plant as a polishing step to remove small flocs or precipitant particles not removed in the settling of coagulated or softened waters. Filtration also can act as a primary turbidity in certain conditions, such as direct filtration of raw water ( Peavy *et al.*, 1985 ). According to Sincero A. P and Sincero G.A (2003), filtration is a unit operation of separating solids from fluids.

Generally, filtration process involved passing the water through a granular medium. Solid will be retained at the filter medium. There are several modes of operation in granular filtration medium. The modes are upflow, biflow, pressure, and vacuum filtration ( Peavy *et al.*, 1985 ). Water will passes through the filter bed and suspended mater will be removed by a series of granular medium. Materials will accumulate within the granular medium and headloss through the filter will starts to build and exceeding the initial value. After some times, the suspended solids in the effluent start to increase beyond acceptable limit and headloss occurs across the filter bed. At this time, the filtration phase is stopped and cleaning process will be done. Filter will be cleaned to remove suspended solids that have accumulated in the granular bed. This process is commonly known as backwashed. Shear forces create by backwash will removed suspended matter and washed it away ( Tchobanoglous *et al.*, 2004 ).

Silica has been the most common media used in granular medium in the traditional filters. In the modern filters the medium usually make use of anthracite coal and garnet sand, or in combination with silica sand. Important properties of these materials are size, size distribution and density. The smaller the size of granular media, the greater filtration efficiency but there is reduction in the flow rate. Larger material

increase pore size, reduce head loss but not the filtration efficiency. Varying size distribution also will affect the performance of filtration. A bed of non uniform medium will stratify with smaller particle causing removal and head loss at the surface. Density of the medium also influent performance of filtration. Lighter material is located above the denser material of the same size. ( Peavy *et al.*, 1985 ).

The first filter used is slow sand filter. These filters consist of fine sand with effective size about 0.2mm. Suspended material mostly removed at the surface of the filter. High head loss produced low flow rate ( 0.12 to 0.32m/h ) resulting construction of large filter. Slow sand filters need space and are consume more money. Furthermore, it also not functions well in high turbid water. Rapid sand filter usually make of in depth 0.6-0.75m bed of silica. Sizes ranges from 0.35 to 1.0mm. Rate of filtration is larger than slow sand filter. Common filtration rate ranges from 2.5 to 5 m/h. This type of filter need frequent backwashing when filtered of turbid water. This is because coagulated water causes binding at the fined grained surface and builds up the head lost ( Peavy *et al.*, 1985 ).

Dual media filter consist of silica sand and anthracite coal. The coal depth is about 0.3-0.6m and the depth of sand is about 0.15-0.4m. There are two size gradations in dual-media filters which are sharp gradation and partial mixing. Large pores in the anthracite remove large particle and flocs and penetrate to the sand layer before it is moved. Head loss will be lower and this will enhance filter runs and filtration rates. Unfortunately, a disadvantage for this type of filter is anthracite material is a loosely material. So, any sudden increased in the hydraulic loading will cause rapid binding in the surface of the sand layer ( Peavy *et al.*, 1985 ).

Mixed media filters are usually constructed from a medium evenly graded from small at the bottom and large at the surface. Usually there is a 0.75m bed with 60 percent anthracite, 30 percent silica sand and 10 percent garnet sand with specific gravity of 1.6, 2.6 and 4.2. Maximum of 1.0mm anthracite and minimum 0.15 for the garnet are used as the effective size. Higher filtration rare will be achieved compare to

rapid sand filter and about the same with dual media filters. The filtration rate is about 10 to 20m/h ( Peavy *et al.*, 1985 ).

**2.3 Filtration methods**

In recent years, various treatment technologies have been employed to enhance water quality by removing inorganic contaminants. Ion exchange resins are able to remove many inorganic metal ions from drinking water including iron and manganese, and the formation of insoluble metal oxides improves the performance delaying the breakthrough of the column (Choo *et al.*, 2005).

According to Choo *et al.*,(2005) tight reverse osmosis (RO) filtration and nanofiltration (NF) membranes were used and compared in the tests of the treatment of contaminated water and wastewater containing $Mn^{2+}$ and $Fe^{2+}$. Obviously, the RO membrane removes manganese better than the NF one, but it still could not meet the WHO guidelines (0.1 mg/L Mn). However, in NF for the treatment of chlorine-free pulp mill bleaching effluent, the polymeric NF membrane provided almost 100% removal of manganese and iron, although the ceramic NF membrane only provided a low removal of metals.

Futhermore Choo *et al.*,(2005) added, a laboratory-made ion exchange UF membrane was tested to remove $Fe^{2+}$ and $Mn^{2+}$, but large amounts of the metal ions (more than 74%) passed through the membrane when humic acid or precipitation were not involved. Microfiltration (MF) after oxidation using potassium permanganate ($KMnO_4$), hydrogen peroxide, and manganese sand filtration was performed to remove iron and/or manganese from groundwater. In the case that $KMnO_4$ was used as an oxidizing agent, the MF experiments were conducted only with a suspension containing the already oxidized iron and manganese. Through this method, there was sufficient removal of the metals. Also, membrane fouling still needed to be rectified though levels were reduced with the Mn sands. Manganese and iron also were found to cause membrane fouling in the treatment of drinking.

Despite the entire advance treatment process, with a correct media, filtration also shows great potential to remove iron from wastewater. Traditionally, silica sand has been the medium most commonly used in granular medium filters. Modern filter applications often make use of anthracite coal and garnet sand in place or in combination with silica sand ( Peavy *et al.*, (1985). The most commonly used filter media are incompressible materials with a fixed porosity between 35 and 50%, such as sand or anthracite ( AWWA and ASCE, 1990 ).

Recently, the development of a synthetic media has made it possible to construct filters with porosities that can be varied from 10 to 90% by compression, such that the porosity can be adjusted according to the quality of the wastewater. This synthetic medium is known as the Fuzzy Filter1 and is available commercially through Schreiber Corporation, AL. The main advantage of the Fuzzy Filter1 is that filtration rates are much higher than the rates achieved with filters composed of incompressible media (Blanca Jimenez *et al.*, 1999). Most of the qualities of water improve after undergone that filtration process for example removal of turbidity is 15.2%.

Tayim and Al-Yazouri, (2005) suggest that systems containing calcium in the form CaO or CaCO3 and carbonates in general, are particularly effective in the removal of heavy metals from wastewater. Thus, natural soils of high calcium and carbonate contents may prove to be useful in this respect. In UAE (United Arab Emirates) local soil is used as a media in the filtration column to test the removal of iron wastewater including iron. Apparently, the percentage removal of iron in untreated wastewater is about 93-100%.

# CHAPTER 3
# METHODOLOGY

## 3.0 Methodology:

### 3.1 Preliminary experiment

Preliminary experiment was done to get the general idea about removal of precipitated iron in water and pilot plant. It is important to do the preliminary experiment because it provides preliminary information and pattern about the experiment. This is useful for future experiment regarding the study of this topic. The overall milestone for FYP is as in the Appendix A

### 3.2 Filtration pilot plant

The pilot plant consists of a column packed with filter media, a transfer pump, sump tanks, a rotameter, a bank of manometer tubes and various valves for flow control and sampling. The filtration column is made of clear acrylic with top and bottom flanges, and inlet and outlet connections. Six sampling ports are provided at a fixed depth interval along a section of the column. Tapping points are also provided along the column for pressure drop measurements. These tapping points are connected with tubings to a bank of manometers. The filter media is supported on some a water distributing material below which is backed by as stainless steel mesh. The test solution is prepared in a sump tank made of stainless steel before being pumped into the column (Figure 1.1).

Filtration column is 250mm in diameter and 3m in height. Thickness of the column wall is 5mm. Fine sand media (350 to 800 micron) will be used as the media of the filtration column. Cylindrical feed tank and rectangular effluent tank both are made

from stainless steel and have 250 L capacity. Type of the feed pump is single impeller centrifugal pump with body, casing and impeller. The feed pump is made from stainless steel and has 90 L/min maximum capacity and 20.7m maximum head. Electrical system for the feed pump consists is 230VAC / 1 phase / 50 hz. In line rotameter for flowmeter is used and ranging from 2.0 to 19.0 LPM. Six tube bank with height 2m of manometer with pressure gauge are used in this pilot plant. The manometer pressure ranges from 0 to 1 bar(g). General requirement for electrical is 230VAC / 1 phase / 50. Water will be supply by the laboratory. Equipment such as vials, stop watch and turbidity meter also are included. Overall dimension, height is 4.15m, 1.22m width and 1.22m depth. Process flow diagram for filtration pilot plant is as in Figure 1.1.

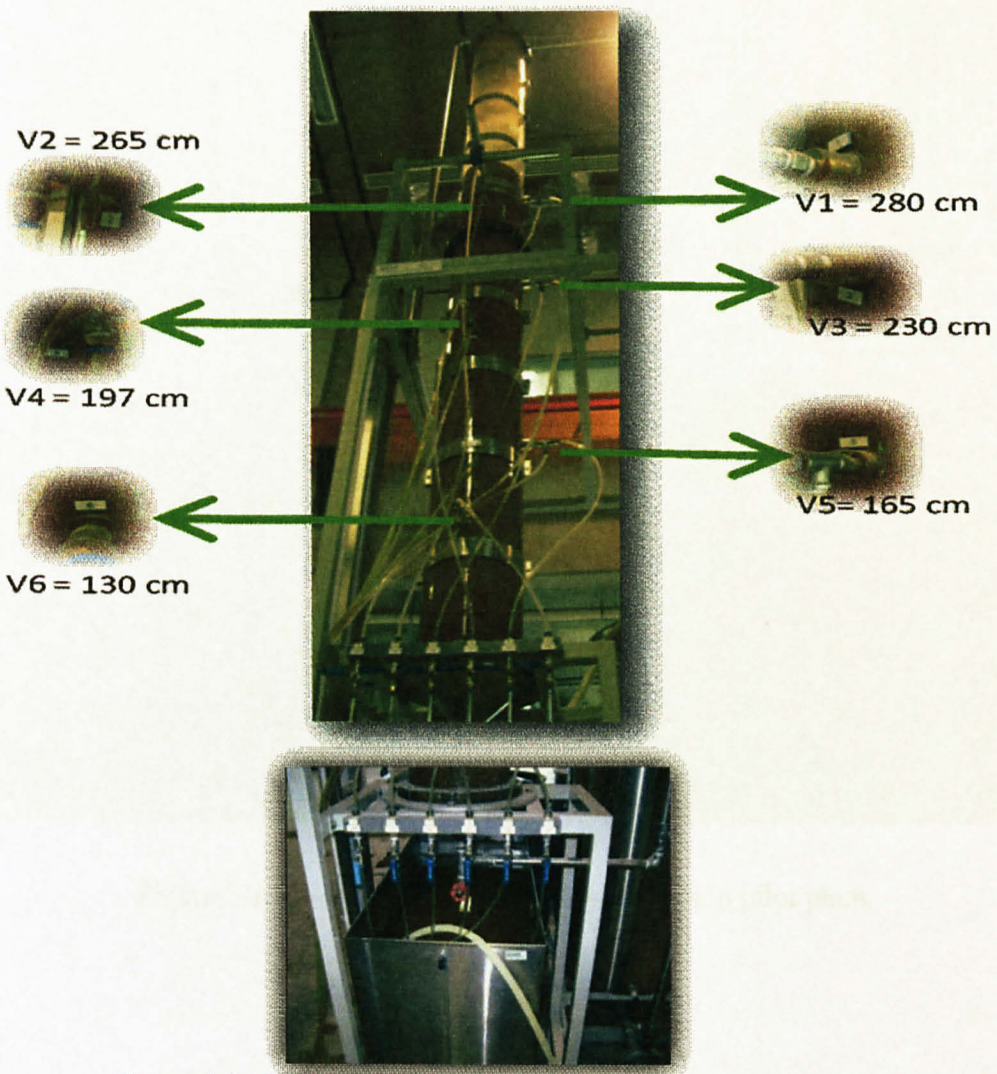


Figure 3.1: Picture filtration pilot plant and its sampling points

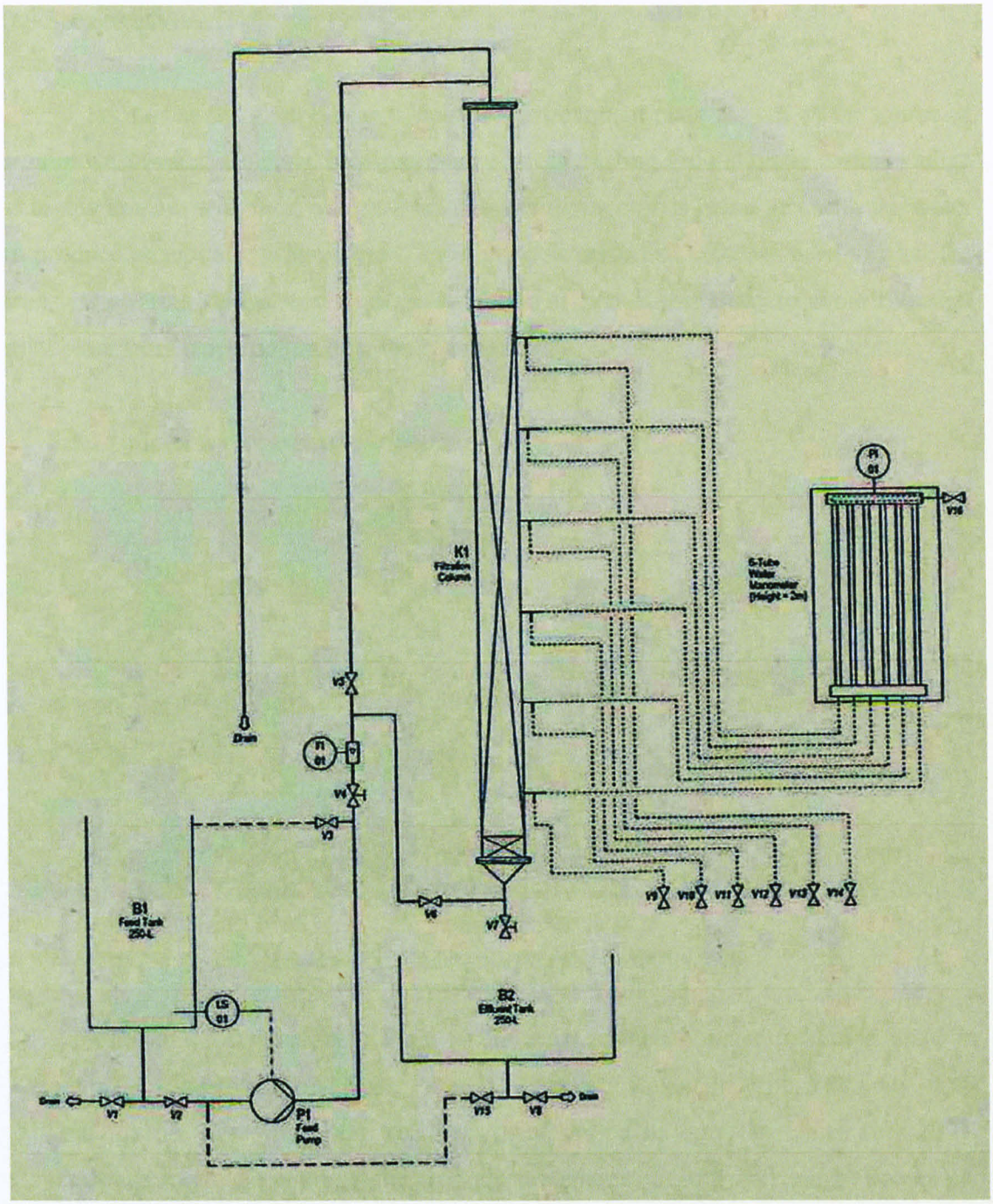


Figure 3.2: Flow chart of process flow filtration pilot plant

### 3.3 Source of iron (Fe)

For this study, sludge from Chicha water treatment plant is used as the source of iron in wastewater. Chicha water treatment plant is treating ground water, so the sludge is highly contain with iron. Sludge from dewatering process is being mix with the water to produce precipitated iron in water. Pilot plant as described before is used to filter the iron wastewater. Sludge was used as the source of iron in this study to avoid filtration pilot plant from being polluted by the wastewater.

#### 3.3.1 Chicha water treatment plant


Figure 3.3: Chicha water treatment plant

Chicha Water Treatment Plant is the most advanced water treatment plant in Kelantan. It is located at Jalan Pasir Puteh, Kota Bharu, Kelantan. With a capacity of 60 million liter per day, this water treatment plant started its operation since July 2003. Chicha water treatment plant get the groundwater sources from 6 well and 36 boreholes. The well is 15 m – 25 m deep which have three aquifer, first, second and third aquifer. This water treatment was developed to cater 80 ML/G, and using groundwater as sources which contains iron (7ppm) and manganese (0.87ppm). These iron and manganese concentration in the water can be considered very high. Basically average flow rate into this water treatment plant is about $2500m^3/h$-$2625m^3/h$. Maximum flow

rate that flow into Chicha treatment plant is 80MLD. This water treatment plant undergoes several processes before water can be distributed to the Kota Bharu and Bachok area (Figure 1.4 and 1.5). The processes are as below:

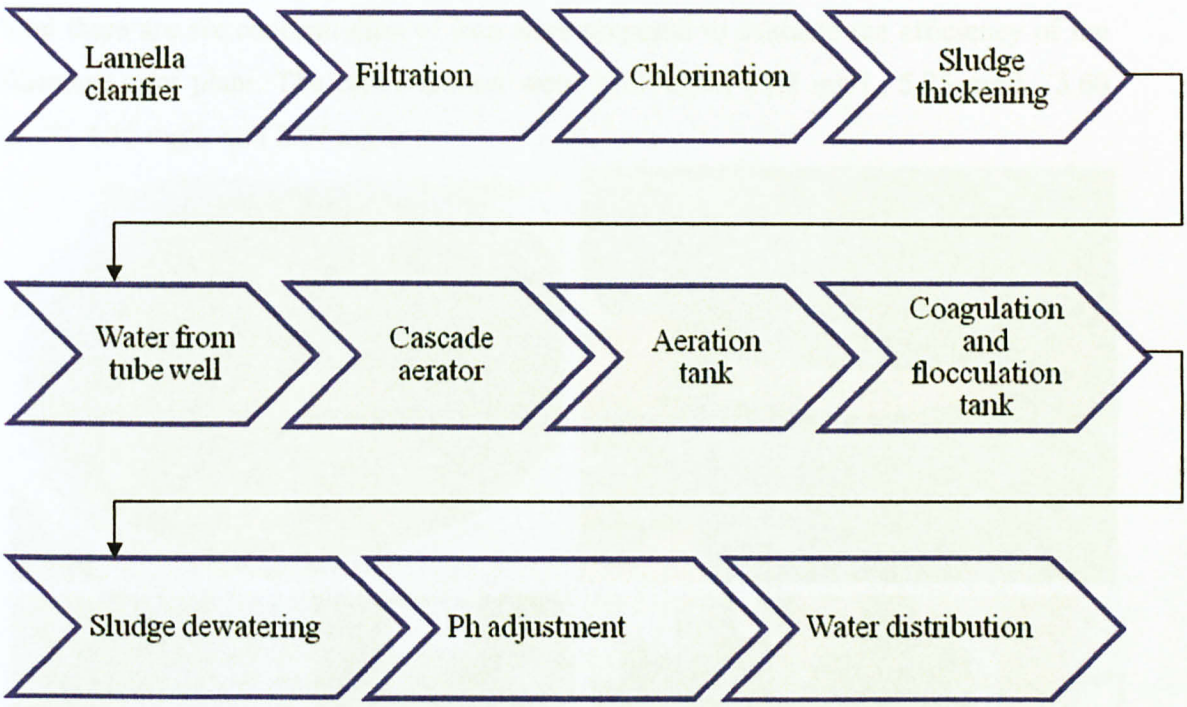


Figure 3.4: Treatment process at Chicha water treatment plant

*( Source: Chicha water treatment plant manual )*

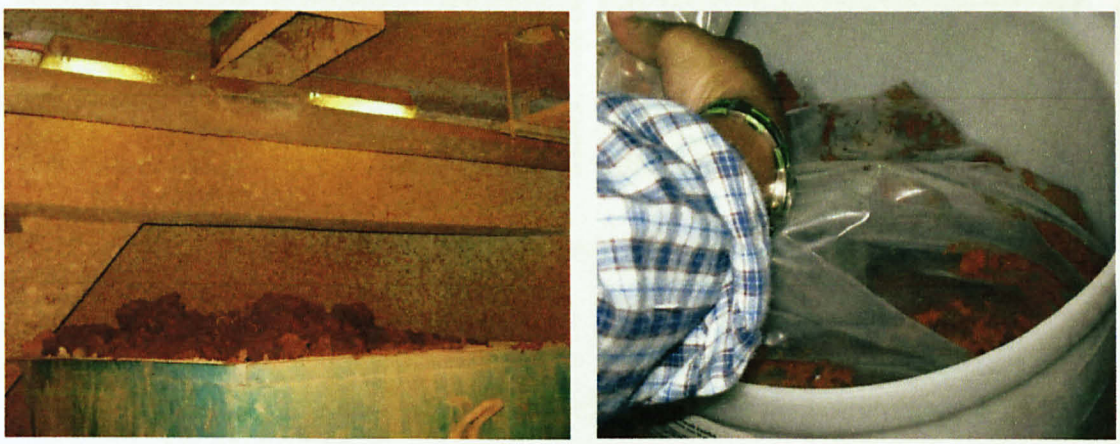

Figure 3.5: Picture of sludge at Chicha water treatment plant

### 3.4 Preparation of water sample

Sludge was mixed with water from the tap in order to get the desired concentration. Trial and error were done until the desired concentration achieved. In total there are six concentration of iron were prepared to evaluate the efficiency of the filtration pilot plant. The concentration were 21.2 mg/L, 11.7 mg/L, 5.75 mg/L, 3.60 mg/L, 3.55 mg/L and 2.07 mg/L.


Figure 3.6: Sludges in the container were mixed with water tap.

### 3.5 Operating filtration pilot plant

Backwashing is done first to avoid clogging so that the performance of filtration pilot plant can be precisely observed. Backwashing is done until the filtration pilot plant is clean and ready to operate (Figure 1.7).

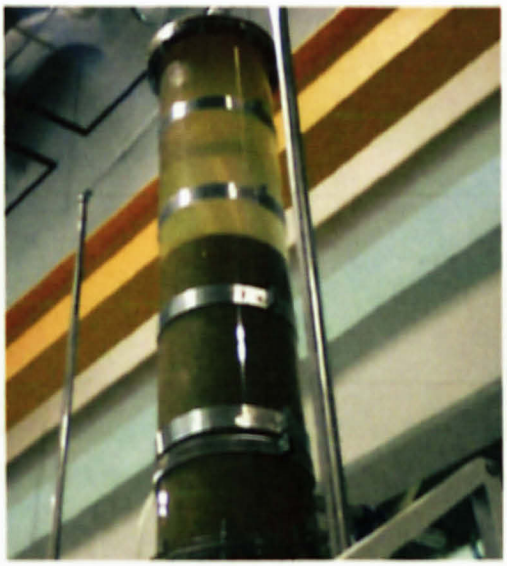

Figure 3.7: Backwashing is done to clean the sand filter

After the pilot plant is ready to be operated, water contains iron are inserted into the pilot plant. Before that, iron concentration was first tested to get the desired iron concentration. Water sample from the filtration pilot plant were collected by closing and opening the valve at filtration pilot plant (Figure 1.1). Initial sample was taken before starting the experiment so that comparison before and after experiment can be analyzed. Equipment and procedure for conducting the experiment are as follow.

**Equipments**

- Filtration pilot plant
- Container for sampling purpose
- Marker
- Turbidimeter
- Spectrophotometer

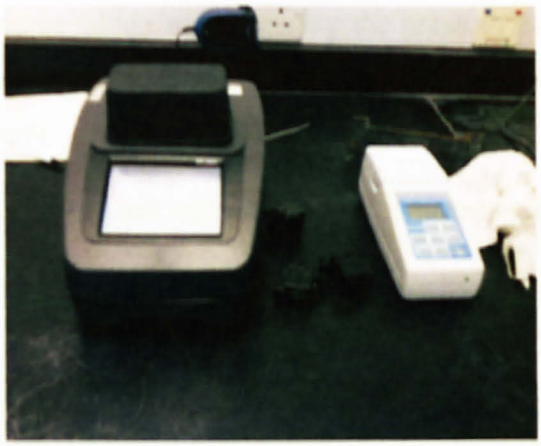

Figure 3.8: Spectrometer and turbidimeter

**Procedure**

1. Containers for sampling purposed are prepared. Container were marked accordingly using marker
2. A known concentration of suspended solids solution in the feed tank B1 is prepared
3. The pump is directed bypass hose into the feed tank B1
4. Valves V2 V5 and V7 is opened
5. Feed pump P1 is switch on. Open and adjust valve V4 to maintain a flow rate as determined during the general start-up procedures; q'
6. Start the timer at t=0
7. Perform the following at every 1 minutes interval:
    I. Collect samples at each valve V9 to V14
    II. Record the pressure measurements until at all 6 tubes in the manometer

8. Samples are continuing taking and recording the pressure measurement until a sharp increase in head loss is observed. This is when the filter media has reached the breakthrough point

9. Feed pump P1 is switch off and valve V5 and V7 is immediately close

10. Measurement for colour, turbidity and iron are performed for every samples collected

### 3.6 Data gathering process

For the data gathering process for iron concentration 2.07 mg/L, 3.55 mg/L and 3.6 mg/L, sample from valve 1 until valve 6 were taken every 1 minutes. The experiment was done for 20 minutes. In total there were about 120 samples that are being taken during the experiment. For experiments above 3.6 mg/L, experiment was done by only using sampling point valve 6. Experiment 11.7 mg/L and 21.2 mg/L was done until the system was clog.

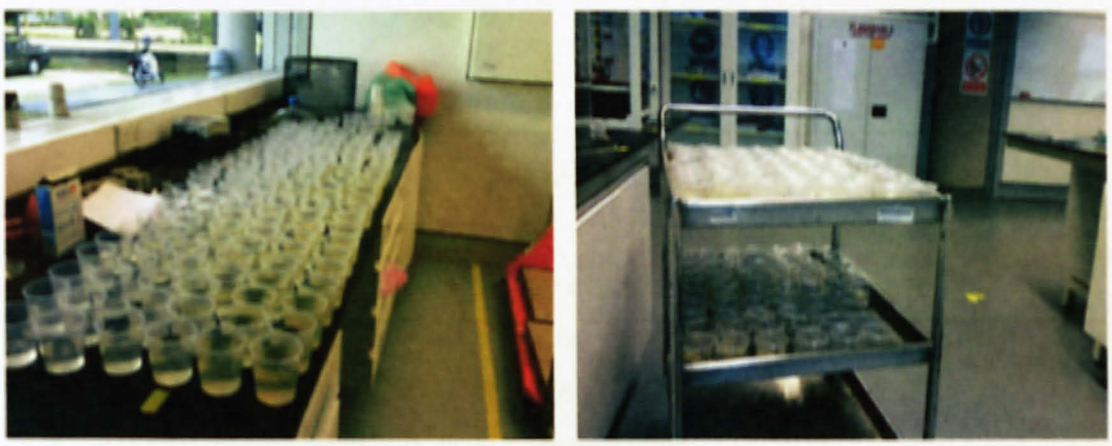

Figure 3.9: Sampling of water sample from respective sampling point

### 3.7 Laboratory testing and experimentation

The samples obtained undergo laboratory testing and experimentation. Universiti Teknologi Petronas Water and Waste Water Engineering laboratory were used for the testing and experimentation activities. The tests that were conducted at the laboratory are colour test, turbidity test and iron concentration test. Iron concentration ware tested by using HACH method.

- **Colour test**

Objective of this test is to determine the apparent or true colour of water sample. Colour may be expressed as apparent or true colour that is the colour of water from which turbidity has been removed. The apparent colour includes that from dissolved materials plus that from suspended matter.

**Equipment**

- Sample cells, 10mL
- Spectrophotometer

**Procedure**

1. Apparatus is assembled
2. Blank sample cell is wiped and inserted into the cell holder with the fill line facing right
3. Zero is pressed. The display show : 0 units PtCo
4. Prepared sample is wiped and inserted it into the cell holder with the fill line facing right. Read is press. Results are in mg/L PtCo. This gives apparent colour
5. Fill the sample cell into 10ml of filtered sample
6. Filtered sample cell is wiped and inserted it into the cell holder with the fill line facing right. Read is press. Results are in mg/L PtCo. This gives true colour value.

Figure 3.10: Preparation of colour test

- **Turbidity test**

Turbidity test is done to determine the turbidity of water sample. The turbidity test measures an optical property of the water sample that result from the scattering and absorbing of light by the particulate matter present.

**Equipment**

- Sample cells with cap
- Turbidimeter, potable
- Water sample

**Procedure**

1. A representative sample is collected in a clean container
2. A sample cell is filled to the line (about 15ml), taking care to handle the sample by the top. Cap the cell
3. The cell is wiped with a soft, lint free cloth to remove water spots and fingerprints
4. The sample cell is placed in the turbidimeter and the turbidity reading is taken.

Figure 3.11: Preparation of turbidity test

- **Iron concentration test**

Iron concentration test is done to measure concentration of iron . HACH method had been used to measure the iron concentration. In this method, ferrover iron reagent powder is being used as the powder pillow. An orange colour formed when iron is present.

**Equipment**

- Sample cells, 10mL
- Spectrophotometer
- Cylinder
- Distilled water
- Beaker
- Ferrover iron reagent powder pillow

**Procedure**

1. Apparatus is assembled
2. Press stored program
3. Select 265, iron ferrover.
4. Prepared samples: Fill a clean square sample cell with 10mL of sample
5. Add the content of one ferrover ion reagent powder pillow to the sample cell. Swirl to mix. An orange colour will form if iron is present.

6. Press timer, ok

   A three minute reaction period will begin

7. Blank preparation

   Fill a second square sample with 10mL of sample

8. When the time expires blank is inserted into the cell holder with the line facing light

   Press Zero

   The display will show 0.00mg/L Fe

9. Place the prepared sample into the cell holder with the fill line facing light.

   Press Read

   Results are in mg/L

10. Procedure were repeated for all the water sample, if the reading was out of spectrophotometer range, the sample is dilute first before the reading is taken

Figure 3.12: Preparation of iron concentration test

Data gathering and laboratory works for the study of removal of iron removal using filtration pilot plant are as in the following flow chart in the next page.

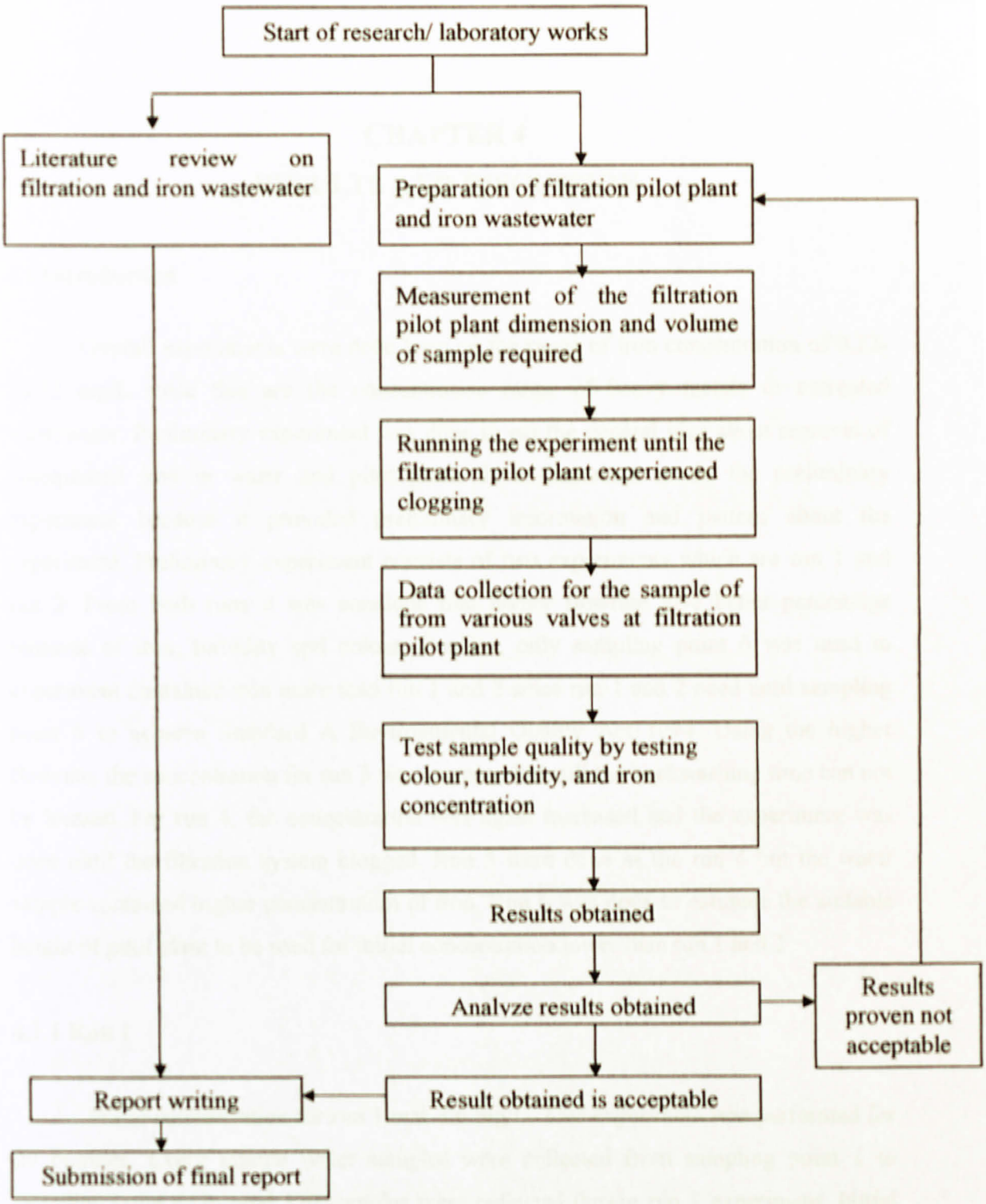


Figure 3.13 : Data Gathering and Laboratory Works

# CHAPTER 4
# RESULTS AND DISCUSSION

## 4.1 Introduction

Overall experiments were done base on the range of iron concentration of 0.12-24.32 mg/L since this are the concentration range of heavy metals in untreated wastewater. Preliminary experiment was done to get the general idea about removal of precipitated iron in water and pilot plant. It is important to do the preliminary experiment because it provided preliminary information and pattern about the experiment. Preliminary experiment consists of two experiments which are run 1 and run 2. From both runs it was conclude that higher flowrate give better percentage removal of iron, turbidity and colour. Besides, only sampling point 6 was used in experiment contained iron more than run 1 and 2 since run 1 and 2 need until sampling point 6 to achieve Standard A Environmental Quality Act 1974. Using the higher flowrate, the concentration for run 3 was increase but still the backwashing time can not be located. For run 4, the concentration was again increased and the experiment was done until the filtration system clogged. Run 5 were done as the run 4 but the water sample contained higher concentration of iron. Run 6 was done to estimate the suitable height of pilot plant to be used for initial concentration lower than run 1 and 2.

### 4.1.1 Run 1

Initial concentration for run 1 was 3.6 mg/L. This experiment was performed for 20 minutes. Every minute water samples were collected from sampling point 1 to sampling point 6. In total 120 samples were collected during run 1 experiment. Initial turbidity and colour for run 1 were 53 NTU and 482 PtCo respectively. Average flowrate of the filtration system was 1.17 m/hr.

All of the samples had been test to measure the colour, turbidity and iron removal. Observation of colour, turbidity and iron concentration can be observed by the results and graph plotted. In general for a 20 minutes experiment, water sample for sampling point 1 and 2 show that measurement for colour, turbidity and iron are not consistent. As for other sampling points which are sampling point 3, 4, 5 and 6, the measurements are quite consistent. (Figure 4.1)

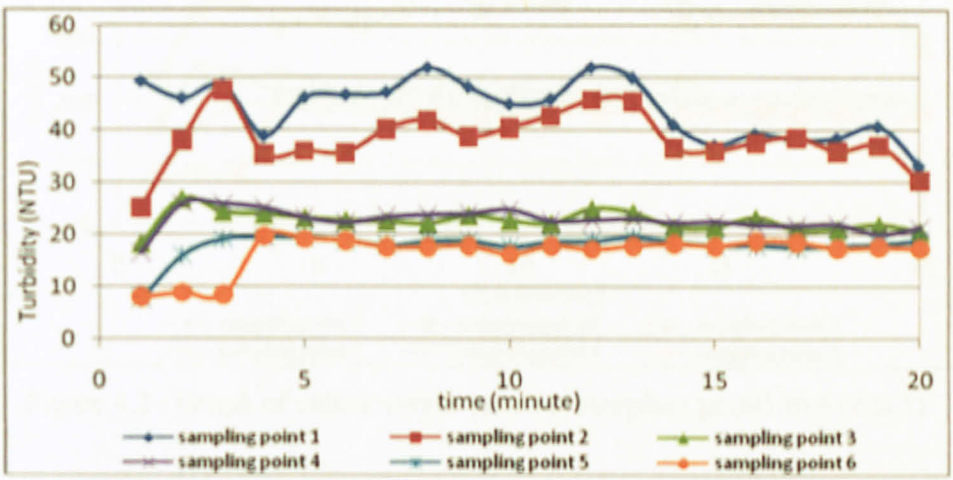


Figure 4.1: Graph of turbidity versus time for sampling point 1 to 6 (run 1)

The data gained from the test performed were analysed using spreadsheet. This is done to know whether there are significance differences in performance of the filtration sampling points as the wastewater undergo the filtration from sampling point 1 to 6. Base on data analysis done to run 1 experiment, there is significant different in removal of turbidity between sampling point 1 and 2. This indicates that performance of turbidity removal in sampling point 2 were different from sampling point 1. Hence, drop in performance were happening as the wastewater undergone from sampling point 1 to 2. This is because the wastewater is in the initial of the filtration process of adjusting to the system. In addition the first sampling point is not far from the discharge point into the filtration pilot plant. Movements of material inside the first sampling point were observed. There are no significance different observed between sampling point 3 and 4. Hence, no drop in performance of turbidity removal happened as the wastewater undergo from sampling point 3 to 4. This is also the same between sampling point 5 and

6. But, significance different were observed between sampling point 1 and 6. Drop in performance of turbidity removal were happened as the wastewater undergone the filtration process. Colour test performed also show the same trend with turbidity test. (Figure 4.2)

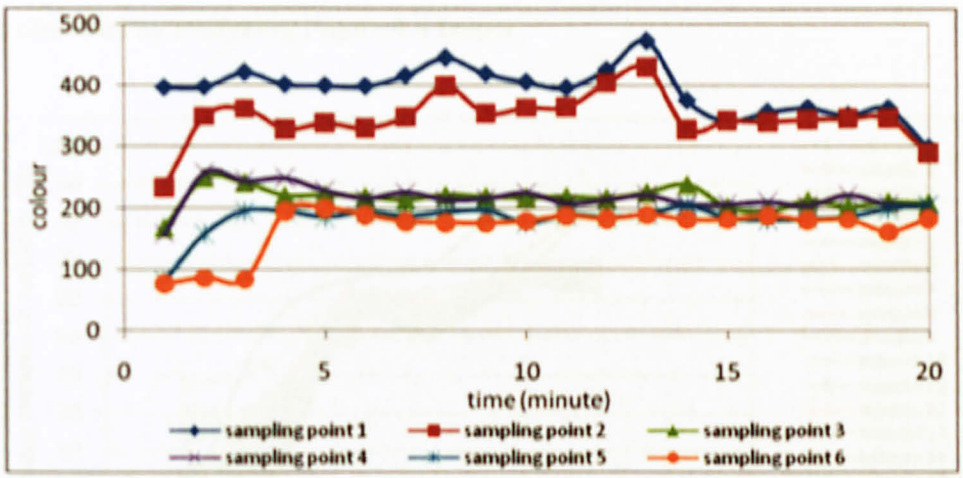


Figure 4.2 : Graph of colour versus time for sampling point1 to 6 (run 1)

Referring to Figure 4.3 iron removals with respect to sampling point are quite different from removal of colour and turbidity. This is justified by the result from the data analysis. No significance different occurred between sampling point 1 and 2, 3 and 4, and 5 and 6. Drop in iron removal is not happening as the wastewater undergone the filtration process. Removal of iron is consistent throughout the filtration pilot plant.

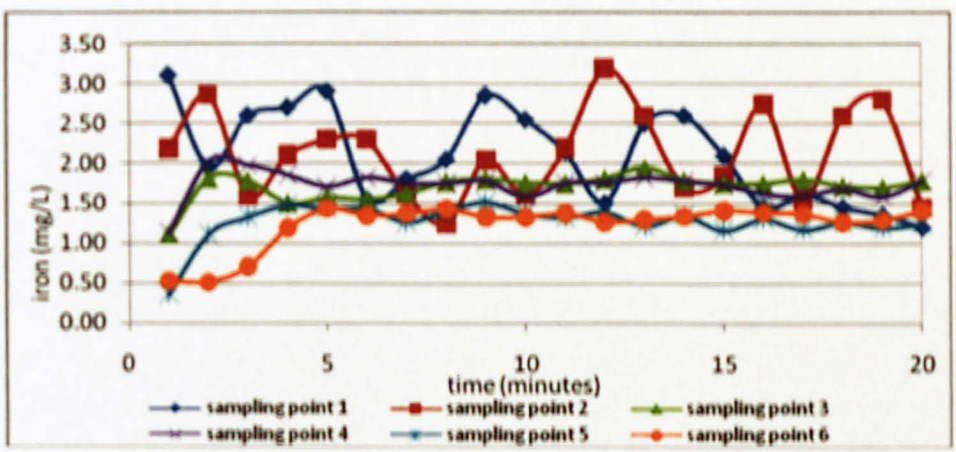


Figure 4.3 : Graph of iron concentration versus time for sampling point 1 to 6 (run 1)

When the time of filtration treatment getting longer, the percentage removal of turbidity, colour and iron also increased. Base on the graph plotted above, the entire three tests showed that the percentage removal increased as the time progress from minute 1 to minute 20. Removal of colour, turbidity and iron are about 60-70%. Removal of turbidity is 69%. The trend of the removal of turbidity with respect to time can be observed by analyzing Figure 4.4 below.

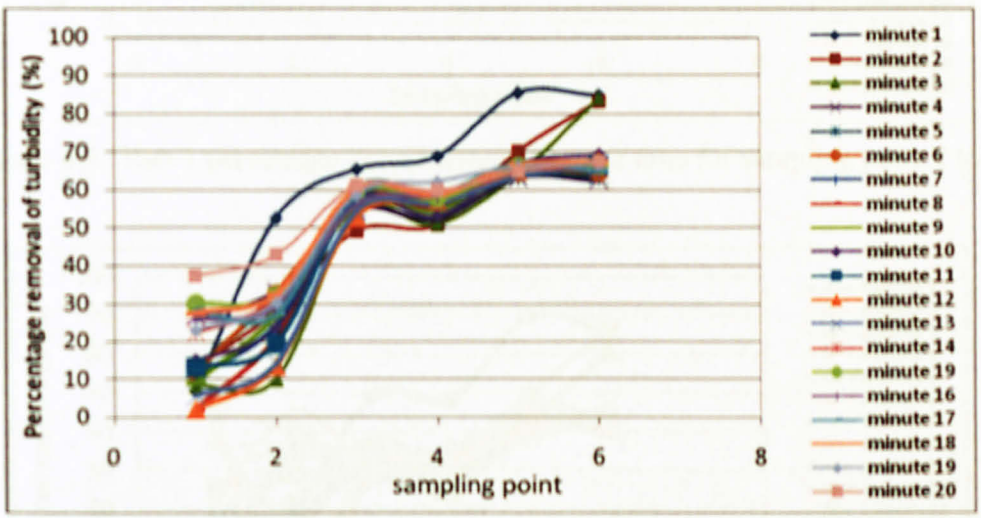


Figure 4.4 : Run 1 percentage turbidity removal versus time for sampling point 1 to 6

By analyzing Figure 4.5, for colour removal, it also shows the same trend with removal of turbidity. As the time increase, the removal of turbidity is also increase. For 20 minutes experiment removal of colour is 65%.

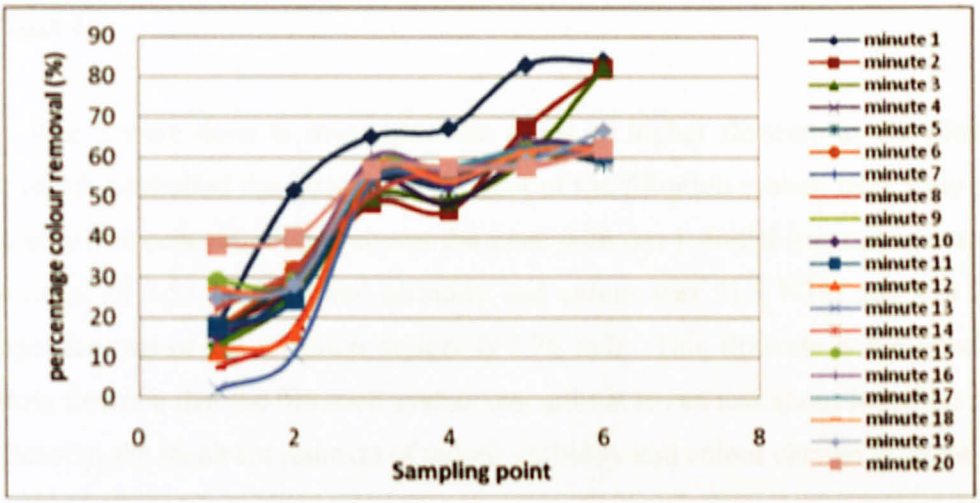


Figure 4.5 : Run 1 percentage colour removal versus time for sampling point 1 to 6

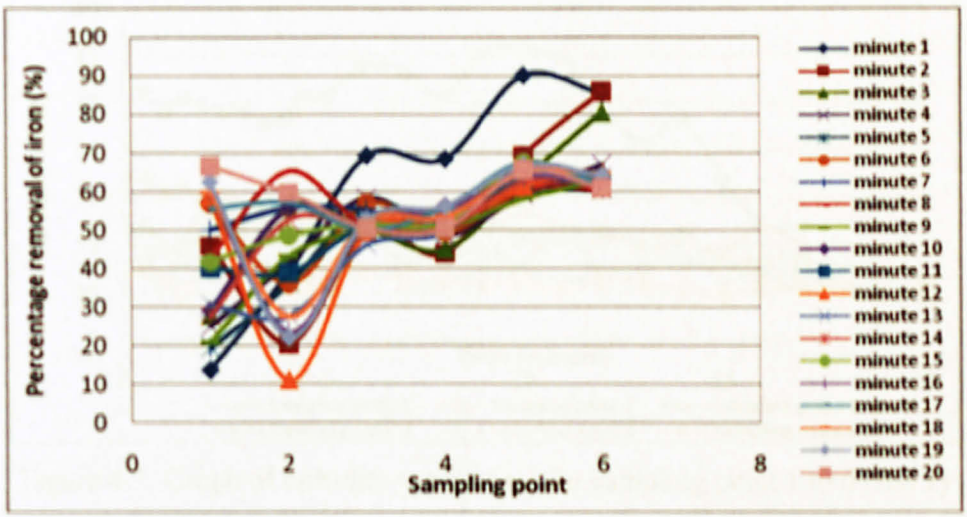


Figure 4.6 : Run 1 percentage iron removal versus time for sampling point 1 to 6

As for concentration of iron, the percentage removal is 66%. It almost the same with turbidity and colour removal. this can be prove by above figure which is figure 1.19. Although the percentage removal of iron is high but still the lowest sampling point which is sampling point 6 higher than 1 mg/L (Figure 4.3). The outcomes of the filtration system still do not meet the standard A environmental quality act 1974 which is 1mg/L or below. Result of iron concentration in sampling point 6 is above 1mg/L.

### 4.1.2 Run 2

Run 2 were done to investigate the effect of higher flowrate to the filtration. Valve which controlled the flowrate of effluent of the filtration system were fully open. In this case iron concentration is almost the same with run 1. Initial iron concentration is in the range of 3.55 mg/L. initial turbidity and colour was 51.5 NTU and 428 PtCo. Average flowrate of the filtration system is 1.76 m/hr. This flowrate is the maximum operating flowrate that the filtration system can affords to run and about twice the run 1. Significantly, the result for removal of colour, turbidity and colour change from run 1.

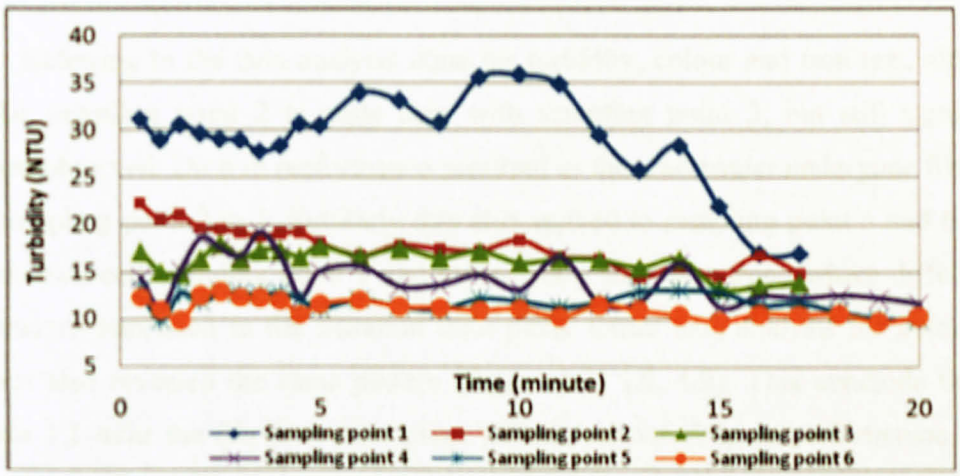


Figure 4.7: Graph of turbidity versus time for sampling point 1 to 6 (run 2)

Base on the Figure 4.7, 4.8 and 4.9, sampling point 1 is no longer near sampling point 2 as in the run 1. Observation for colour, turbidity and iron concentration revealed that sampling point 2 is much nearer to sampling point 3. On the other hand, sampling point 3 also change where it is not near to sampling point 4. Graph plotted showed that neither sampling point 3 or 5 is near to the graph of sampling point 4. Despite that, graph plotted for sampling point 5 and 6 still in same range as run 1 (Figure 4.7, 4.8, 4.9). This occurred mostly because of the higher flowrate of the filtration system. Higher flowrate will increase the fluctuation in the filtration system thus affecting the performance of colour, turbidity and iron removal.

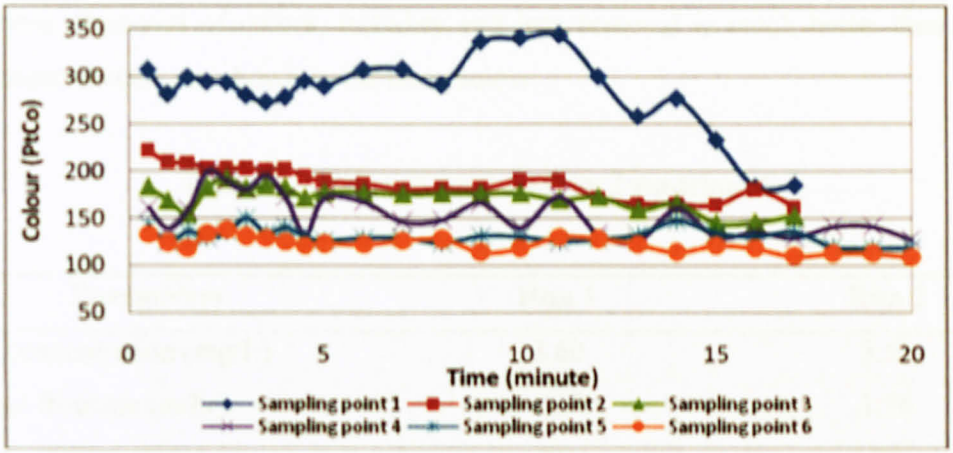


Figure 4.8: Graph of colour versus time for sampling point 1 to 6 (run 2)

Referring to the data analysis done for turbidity, colour and iron test, although data for sampling point 2 is quite near with sampling point 3, but still significant different observed. Drop in performance occurred as the wastewater undergone filtration from sampling point 2 to 3. Similarly this also applied to sampling point 5 and 6. Data analysis between sampling point 1 and 6 also show the same trend where different in performance happened in the filtration pilot plant. Other data analysis for colour and iron test also revealed the same pattern (Figure 4.7, 4.8, 4.9). This conclude that for flowrate 1.1 m/hr the filtration pilot plant will experience drop in performance as the wastewater undergo filtration from sampling point 1 to 6.

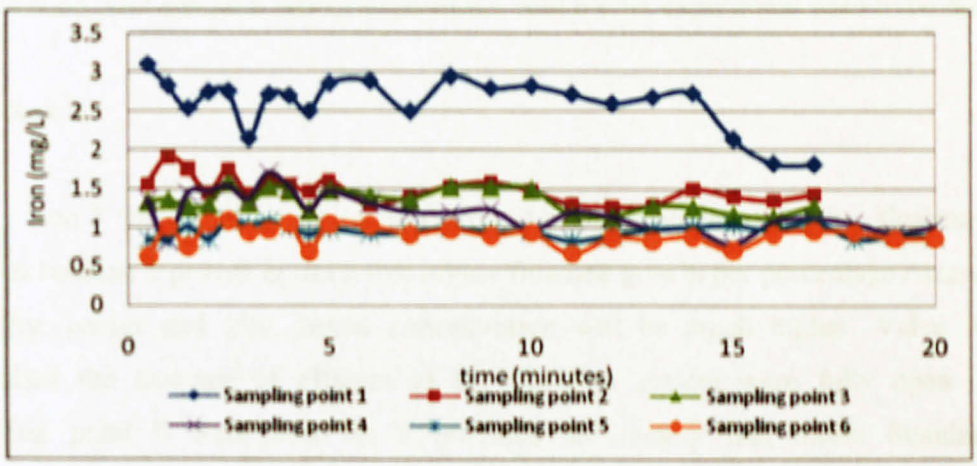


Figure 4.9: Graph of iron concentration versus time for sampling point 1 to 6 (run 2)

Beyond expectation the outcome of filtered wastewater is indeed quite acceptable. Removal of colour, turbidity and iron removal is much better than run 1 experiment. Details are shown in the table below:

Table 4.1: Table of run 1 and run 2 experiment

| Parameters | Run 1 | Run 2 |
|---|---|---|
| Initial concentration (mg/L) | 3.60 | 3.55 |
| Average flowrate (m/hr) | 1.17 | 1.76 |
| Turbidity removal (%) | 69 | 78 |
| Colour removal (%) | 65 | 71 |
| Iron removal (%) | 66 | 75 |

Although the significance different are observed in most of the data in run 2 but the filtration pilot plant still capable producing better result in term of turbidity, colour and iron removal. In addition, the iron concentration from sampling point 6 is below 1 mg/L. These follow the Standard A Environmental Quality Act 1974. Besides, it also indicate that for experiment with concentration 3.6 mg/L and above, the iron need to be filtered till valve 6 because for Run 2 (3.6 mg/L iron concentration experiment) previously showed that standard A only can be achieved when the precipitated iron in water pass through sampling point 6. In order to determine the maximum capacity that the filtration pilot can take further experiment with higher experiment need to be done.

### 4.1.3 Run 3

Run 3 were done as the continuation of run 2 experiment. Higher flowrate will be used because it proves in run 2 that higher flowrate give better percentage removal of turbidity, colour and iron. Initial concentration will be much higher. Valve which controlled the flowrate of effluent of the filtration system were fully open. Only sampling point 6 were used as it provides the quality that meets Standard A Environmental Quality Act 1974. The aim is to study the effect of higher concentration

to the filtration system and locate the backwashing time. The duration of the experiment was the same as previous two runs which is 20 minutes. Initial iron concentration is in the range of 5.75 mg/L. Initial turbidity and colour were 31.9 NTU and 395 PtCo respectively.

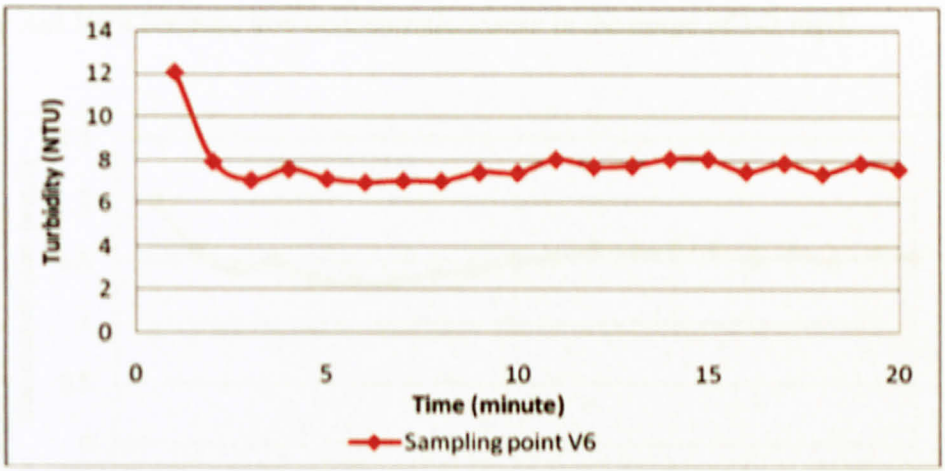


Figure 4.10: Graph of turbidity versus time for 5 mg/L iron concentration (run 3)

Referring to Figure 4.10 the turbidity is in the range 6 to 8 NTU. In 20 minutes experiment still clogging is not occurred. Removal of turbidity is 76% which is quite high. The same trend also happened to graph colour (Figure 4.11)

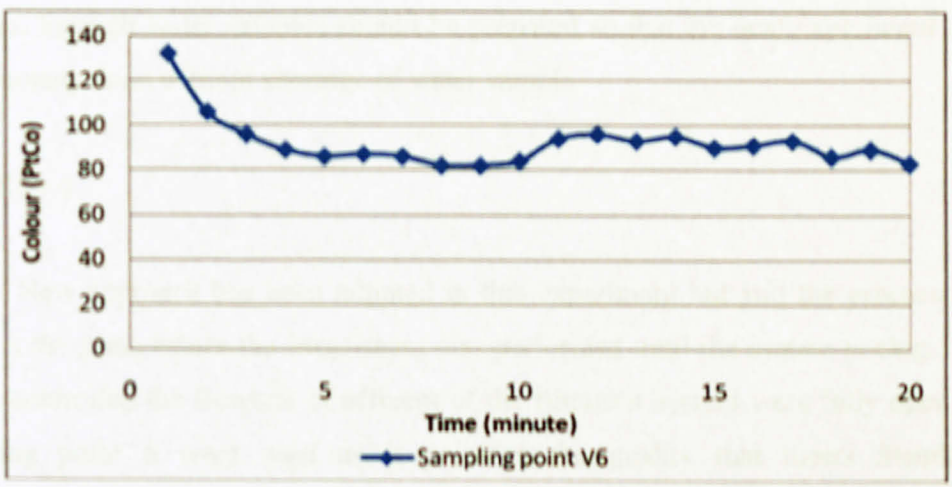


Figure 4.11: Graph of colour vs time for 5.75 mg/L iron concentration (run 3)

Base on the graft above, colour for 20 minutes showed in the range of 100-80 PtCo. Removal of colour is 76%. Clogging still do not occurred in 20 minutes time. Percentage removal of iron also in the range of both colour and turbidity. Percentage removal for iron is 74% which is actually quite high (Figure 4.12). Iron concentration is more than 1 mg/L which indicate that the water quality in the Standard B Environmental Quality Act 1974 because iron concentration were in the range of 1-2 mg/L.

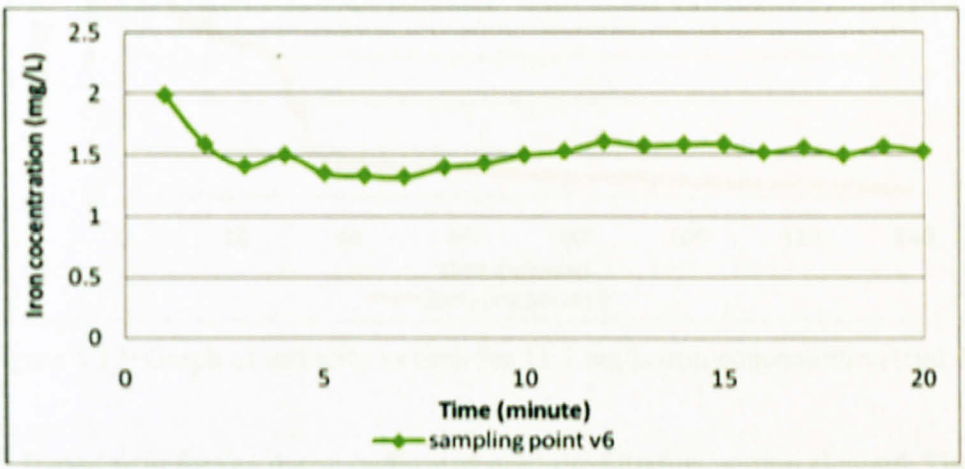


Figure 4.12: Graph of iron vs time for 5.75 mg/L iron concentration (run 3)

By referring to the three tests performed, still the clogging does not occurred. This means that the duration of the experiment should be longer which more than 20 minutes. Enough water samples should be prepared so that the next experiment can be continuously done without shortage of water sample.

### 4.1.4 Run 4

New approach has been adopted in this experiment but still the essence of the study is the same where the experiment was performed until the system is clog. Valve which controlled the flowrate of effluent of the filtration system were fully open. Only sampling point 6 were used as it provides the quality that meets Standard A Environmental Quality Act 1974. The aim is to study the effect of higher concentration to the filtration system and locate the backwashing time. The duration of the experiment

was not the same as previous two runs. Initial iron concentration is much higher than previous experiment which is 11.7 mg/L. Initial turbidity and colour were 75.44 NTU and 407 PtCo respectively.

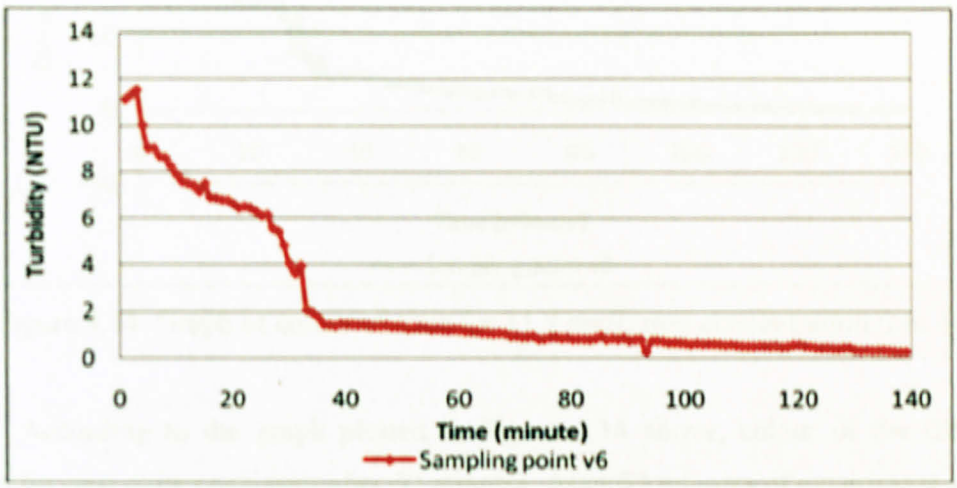


Figure 4.13: Graph of turbidity vs time for 11.7 mg/L iron concentration (run 4)

Experiment for run 4 was performed until the filtration system clogged. The total duration for the filtration system to clog is 139 minutes which 2 hour and 19 minutes. Every minute water sample were collected from sampling point 6. Base on graph plotted in Figure 4.13 above, turbidity of the filtration system become quite consistent after 35 minutes. After 35 minutes of experiment, turbidity for water sample becomes quite stable which are in the range of 0-2 NTU. This indicate that at the 35 minute backwashing should be done because turbidity removal is quite consistent and no further dramatic removal of turbidity can be achieved. In addition to that, after 35 minutes the flowrate become very low and it is not suitable to continue the filtration pilot plant because amount of water that can be filter is very small which is in the range of 10 mL/s.

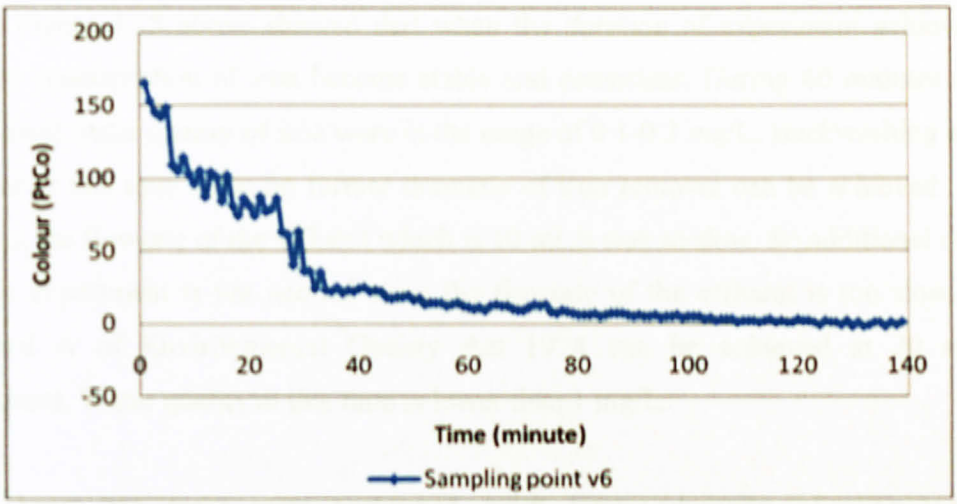


Figure 4.14: Graph of colour vs time for 11.7 mg/L iron concentration (run 4)

According to the graph plotted in Figure 4.14 above, colour of the filtration system become quite consistent after 32 minutes. After 32 minutes of experiment, colour for water sample becomes quite stable which are in the range of 0-20 PtCo. Backwashing should be done at 32 minute because iron removal is quite consistent. Furthermore, after 35 minutes the flowrate become very low hence it is not suitable to continue the filtration pilot plant because flowrate of the effluent is become very small which are in the range of 10 mL/s.

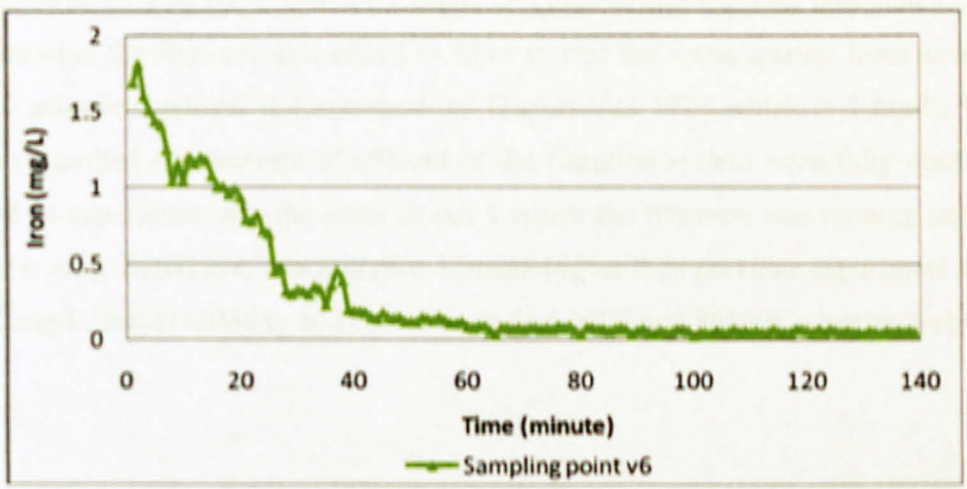


Figure 4.15: Graph of iron vs time for 11.7 mg/L iron concentration (run 4)

Figure 4.15 above showed that when the duration of experiment achieved 40 minutes concentration of iron become stable and consistent. During 40 minutes of the experiment water quality of iron were in the range of 0.1-0.2 mg/L. Backwashing should be done at this time since no further dramatic of iron removal can be achieved. At 40 minutes, the flowrate of the effluent which is 10 mL/s was so slow. So additional of time for this experiment is not needed since the flowrate of the effluent is too slow. Also Standard A of Environmental Quality Act 1974 can be achieved at 20 minute experiment. Water quality at this time is lower than 1 mg/L.

From the three tests performed, with longer duration of experiment at concentration of iron 11.7 mg/L, we can locate the backwashing time for the filtration pilot plant. Backwashing times according to turbidity, colour and iron concentration were 35 minutes, 32 minutes and 40 minutes. Base on the three water quality tests, the earliest from the three tests were taken. Backwashing time for iron concentration of 11.7 mg/L or below is after 32 minutes of experiment.

### 4.1.5 Run 5

This experiment were performed to know the backwashing time for higher concentration of iron more than 11.7 mg/L and also to test up until how much of the concentration the filtration can afford to filter so that the water quality from sampling point 6 achieve Standard B Environmental Quality Act 1974 which is 5 mg/L. Valve which controlled the flowrate of effluent of the filtration system were fully open. The method of experiment was the same as run 4 where the filtration was running until the system is clog. Initial iron concentration is much higher than previous experiment which is 21.2 mg/L. Initial turbidity and colour were 65.6 NTU and 968 PtCo respectively.

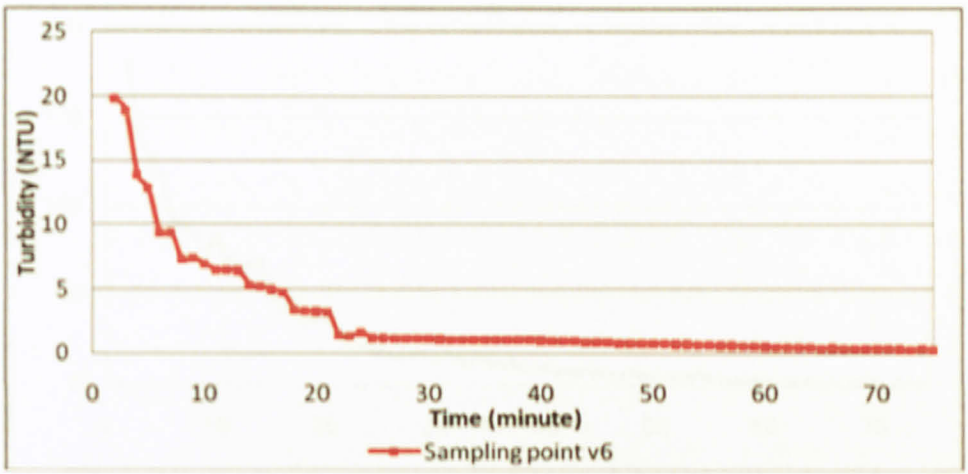


Figure 4.16: Graph of turbidity vs time for 21.2 mg/L iron concentration (run 5)

Experiment for run 5 was performed until the filtration system clogged. The total duration for the filtration system to clog is 75 minutes which 1 hour and 15 minutes. The time for the filtration pilot plant to clog is much earlier than run 4. This occurred because the concentration of iron in this experiment was much higher which was double than previous run. Every minute water sample were collected from sampling point 6. Base on graph plotted in Figure 4.16 above, turbidity of the filtration system become quite consistent after 22 minutes. After 22 minutes of experiment, turbidity for water sample becomes quite stable which are in the range of 0-2 NTU. This indicate that at the 22 minute backwashing should be done because turbidity removal is quite consistent and no further dramatic removal of turbidity can be achieved. In addition to that, after 22 minutes the flowrate become very low and it is not suitable to continue the filtration pilot plant because amount of water that can be filter is very small which is in the range of 10 mL/s.

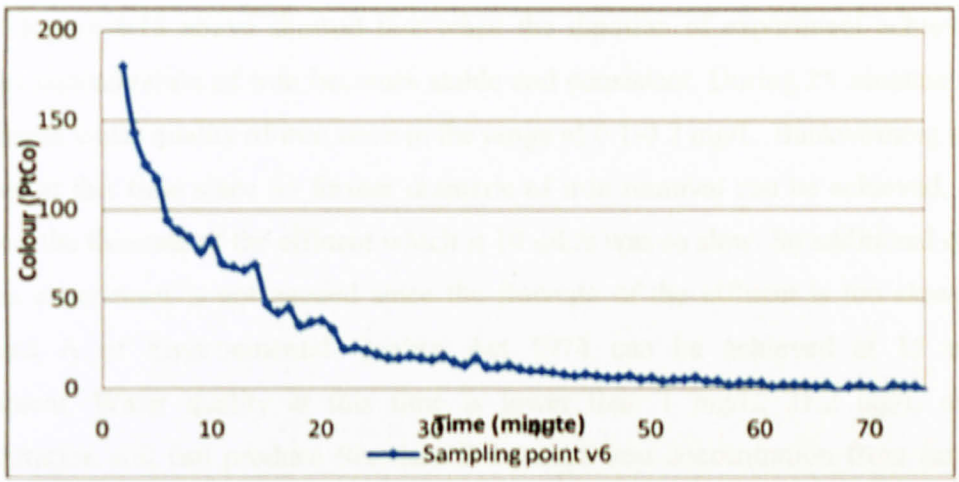


Figure 4.17: Graph of colour vs time for 21.2 mg/L iron concentration (run 5)

According to the graph plotted in Figure 4.17 above, colour of the filtration system become quite consistent after 23 minutes. After 23 minutes of experiment, colour for water sample becomes quite stable which are in the range of 0-20 PtCo. Backwashing should be done at 23 minute because iron removal is quite consistent. Furthermore, after 23 minutes the flowrate become very low hence it is not suitable to continue the filtration pilot plant because flowrate of the effluent is become very small which are in the range of 10 mL/s.

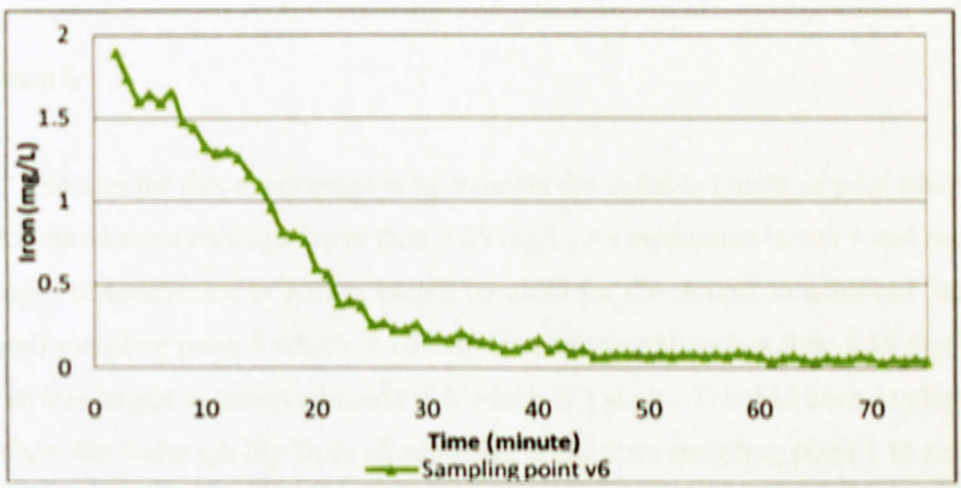


Figure 4.18: Graph of iron vs time for 21.2 mg/L iron concentration (run 5)

Figure 4.18 above showed that when the duration of experiment achieved 25 minutes concentration of iron becomes stable and consistent. During 25 minutes of the experiment water quality of iron were in the range of 0.1-0.2 mg/L. Backwashing should be done at this time since no further dramatic of iron removal can be achieved. At 25 minutes, the flowrate of the effluent which is 10 mL/s was so slow. So additional of time for this experiment is not needed since the flowrate of the effluent is too slow. Also Standard A of Environmental Quality Act 1974 can be achieved at 15 minute experiment. Water quality at this time is lower than 1 mg/L. 21.2 mg/L of iron concentration still can produce Standard B because iron concentration from sampling point 6 is between 2-0.2 mg/L. This indicate that the filtration pilot plant capable to filter iron more than 21.2 mg/L until sampling point 6 become more than Standard B which is 5 mg/L.

Base on the three tests performed with initial iron concentration 21.2 mg/L, we can locate the backwashing time for the filtration pilot plant. Backwashing times according to turbidity, colour and iron concentration were 22 minutes, 23 minutes and 25 minutes. Base on the three water quality tests, the earliest from the three tests were taken. Backwashing time for iron concentration of 21.2 mg/L or below is after 22 minutes of experiment.

### 4.1.6 Run 6

The aim for this experiment is to estimate the suitable height of pilot plant to be used for initial concentration lower than 3.55 mg/L. As mentioned in run 1 and run 2 for 3.55 mg/L concentration or above, height required for the sample to achieved Standard A is until sampling point 6 which is 165cm. Iron concentration less than 3.55 mg/L may required less height to achieve Standard A which is 1 mg/L. This had been implemented by analyze the water quality from all sampling point from sampling point 1 to sampling point 6. Valve which controlled the flowrate of effluent of the filtration system were fully open. Initial concentration for run 6 was 2.07 mg/L. This experiment was performed until the water sample in the tank finish. Run 6 took 14 minutes to finish.

Every minute water samples were collected from sampling point 1 to sampling point 6. In total 84 samples were collected during run 6 experiment. Initial turbidity and colour for run 6 were 7.92 NTU and 111 PtCo respectively.

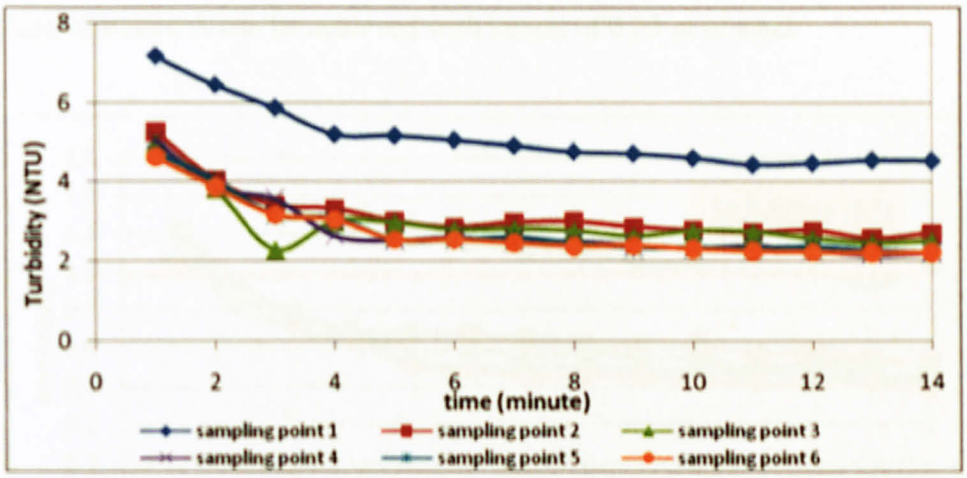


Figure 4.19: Graph of turbidity vs time for 2.07 mg/L iron concentration (run 6)

All of the samples had been test to measure the colour, turbidity and iron removal. Observation of colour, turbidity and iron concentration can be observed by the results and graph plotted in Figure 4.19, 4.20 and 4.21. In general for a 14 minutes experiment, for turbidity measurement to achieve 3 NTU it only required height of sampling point 2.

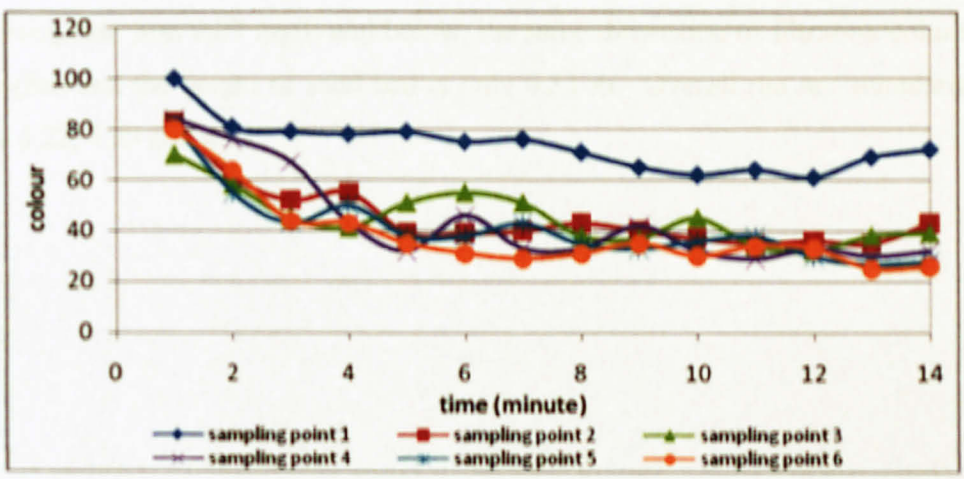


Figure 4.20: Graph of colour vs time for 2.07 mg/L iron concentration (run 6)

Referring to the figure 4.20 above, to achieve 40 PtCo colour of effluent, only height of sampling point 2 is required. This also happened in iron removal graph. Figure 4.21 below show that to achieve Standard A Environmental Quality Act 1974, only height of sampling point 2 is needed. By using the same dimension of this filtration pilot plant, Standard A can be achieved with height of 0.33 m of sand.

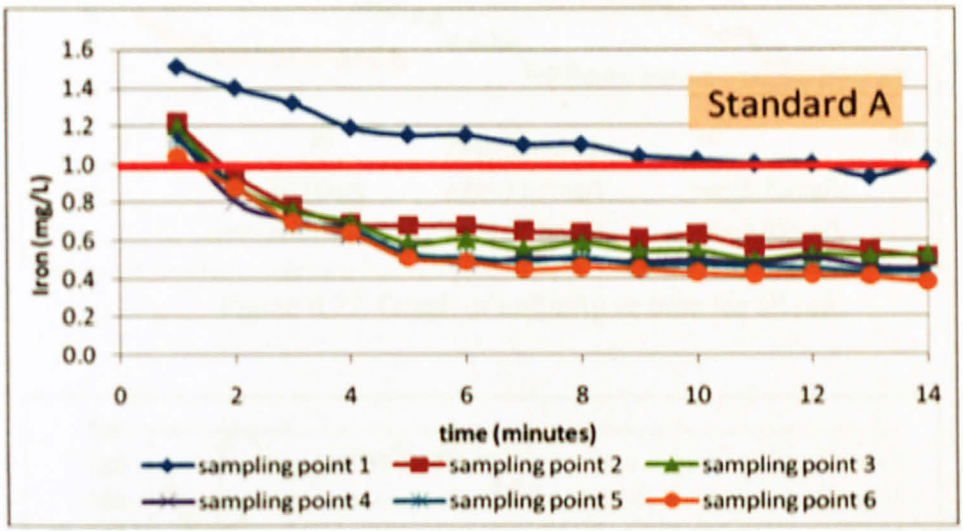


Figure 4.21: Graph of iron vs time for 2.07 mg/L iron concentration (run 6)

As proved in the iron measurement above, suitable height needed to achieve Standard A is different if the concentration of iron different. For concentration 2.07 mg/L of iron or below, only height of sampling point 2 is needed. This means that to treat precipitate iron 2.07 mg/L and below, the same dimension of filtration column can be adopted and the height of sand bed is only 0.33 m. Overall run are summarized in Figure 4.22, 4.23 and 4.24.

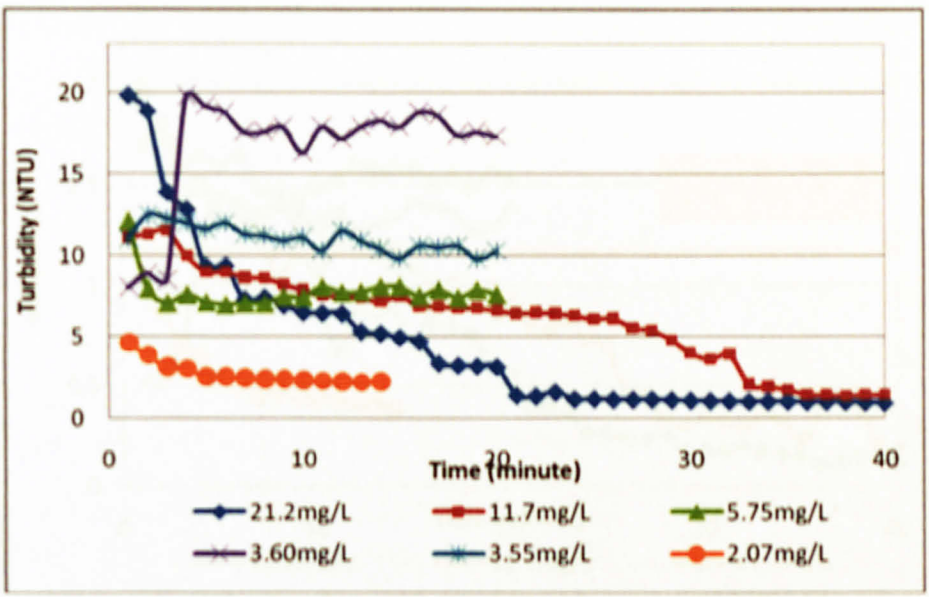


Figure 4.22: Graph of turbidity vs time for all run

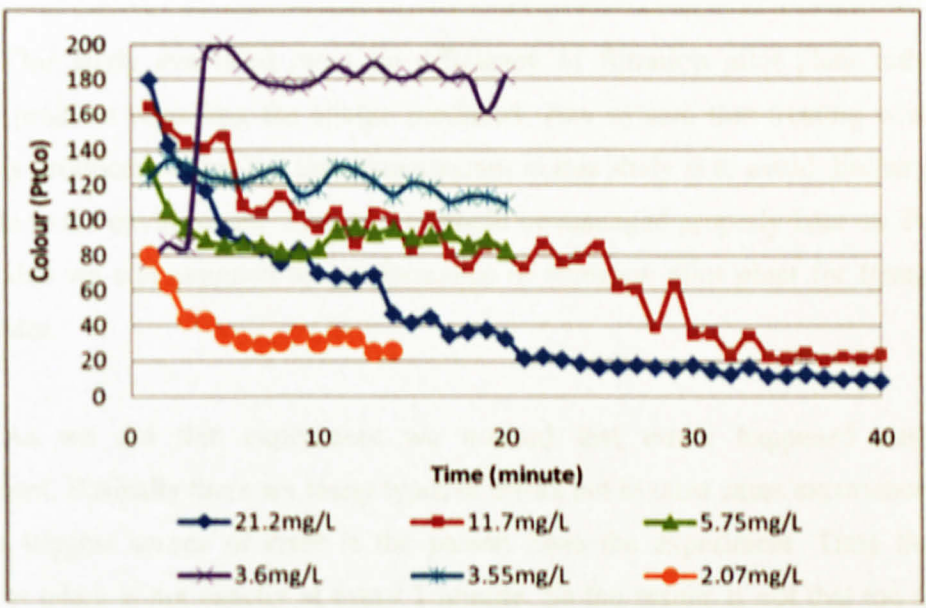


Figure 4.23: Graph of colour vs time for all run

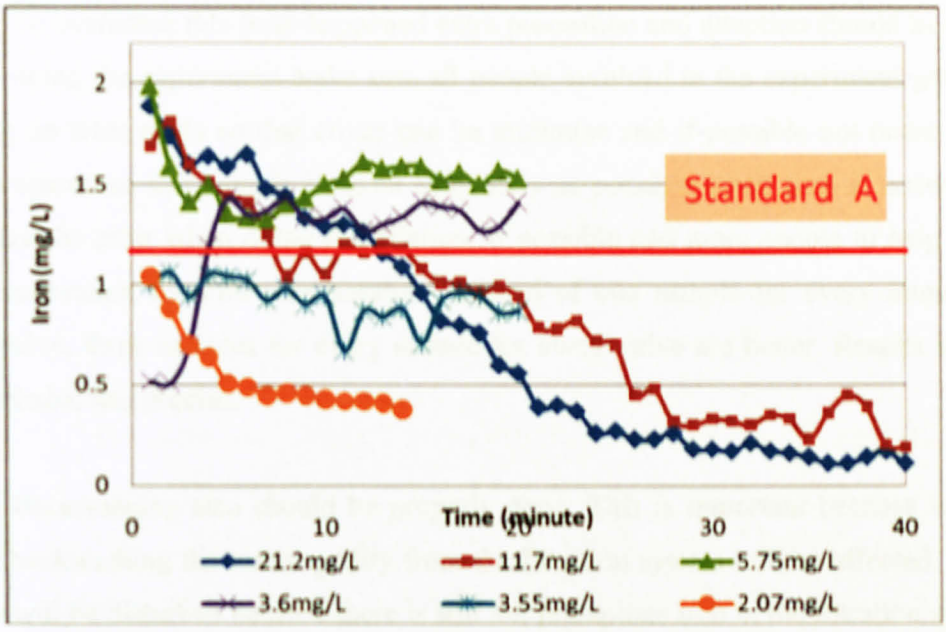


Figure 4.24: Graph of iron vs time for all run

This study evaluated more on efficiency of filtration pilot plant rather than solving problem regarding the sludge produced. Any system that treating wastewater generally produced sludge but the main concern in this study is to avoid discharging the pollution to the environment. The sludge should be managed properly later on. From the results also we can assumed the performance of filtration pilot plant for treating iron wastewater.

As we did this experiment we noticed that errors happened during the experiment. Basically there are many types of errors but in most cases experience shown that the biggest source of error is the person done the experiment. Time the water sample is taken is not exactly at every 1 minute. So the results is not that too accurate because consistency in taking the data is not there. Parallax errors also happened in this experiment. Some of the water samples need to be diluted before performing the iron test. A slight different in diluting the water sample will result inconsistency in the iron concentration. Time is the major constrain here. Water sample that need to be analyze are many but the time left is not much. Every test need to be quick and precise. So the tendency to make mistake is high.

To overcome this from happened extra precaution and attention should be taken. Before doing the experiment make sure all people involved in the experiment got clear briefing on what to do so that errors can be minimize and if possible not occur at all. Well prepared so that sample is taken as quickly as possible when time is arrived. To minimize the error when doing the dilution, if possible add more people to help doing the measurement for iron concentration. Instead of one sample for every minute for every valve, three samples for every minute for every valve are better. Results will be more reliable and precise.

Backwashing also should be properly done. This is important because without proper backwashing the water quality from the filtration system will be affected. Water quality will be disturbed because there is still left precipitate iron in the filtration system.

# CHAPTER 5
# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

Objective of the study which is to find the best efficiency for filtration pilot plant is achieved. Higher flowrate will give better removal of iron, turbidity, and colour. Backwashing time depend on removal of iron concentration, turbidity and colour. Backwashing time can be taken by taking the time before the water quality of the system become stable and consistent. Backwashing time for 11.7 mg/L of iron concentration or below is 32 minutes of experiment. Backwashing time for 21.2 mg/L of iron concentration or below is 22 minutes of experiment. For the second objective, the filtration pilot plant capable to filter precipitate iron more than 21.2 mg/L since the water quality still do not meet Standard B Environmental Quality Act 1974 (5 mg/L). Concentration of iron lower than 2.02 mg/L just need the height of sampling point 2 which is 0.33 m to achieve Standard A Environmental Quality Act 1974.

## 5.2 Recommendations

To improve the results and findings some changes has to be made. The changes are:

- For experiment with concentration 5.75 mg/L, 3.55 mg/L, 3.60 mg/L and 2.07 mg/L, the duration of the experiment should be extended until the filtration system experienced clogging so that backwashing time can be located.
- Work with higher concentration of iron more than 21.2 mg/L with increment of 10 mg/L until sampling point 6 achieve Standard B Environmental Quality

Act 1974 (5 mg/L). This will enable us to predict the backwashing time for different concentration according to water quality tests.

- Work with higher concentration of iron more than 21.2 mg/L with increment of 10 mg/L and predict the height of sand bed to achieve Standard B (5 mg/L)
- Work with concentration lower than 3.55 mg/L but higher than 2.07 mg/L to see what height of sand bed is required to achieved Standard A (1 mg/L)
- More organize when doing the experiment. All the samples must be taken on time and if possible add the manpower to do the experiment
- Give extra precaution and attention when doing the experiment and laboratory measurement so that mistakes and errors can be reduced. This will give better and reliable results.

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# APPENDIXES

Appendix A: Gantt chart
Appendix B: Table of results
Appendix C: Data analysis of run 1 and run 2 experiments


Project: PHP gannt chart DW
Date: Thu 5/28/09
Critical
Critical Split
Critical Progress
Task
Split
Task Progress
Baseline
Baseline Split
Baseline Milestone
Milestone
Summary Progress
Summary
Project Summary
External Tasks
External Milestone
Deadline

## Appendix B

**Run 1**
Initial iron concentration = 3.6 mg/L
Initial turbidity = 53 NTU
Initial colour = 482 PtCo
Average Flow rate = 150 mL/s

**Turbidity test (NTU)**

| Time (minute) | Sampling point | | | | | |
|---|---|---|---|---|---|---|
| | v1 | v2 | v3 | v4 | v5 | v6 |
| 1 | 49.3 | 25.1 | 18.3 | 16.5 | 7.66 | 8.02 |
| 2 | 46.1 | 38.1 | 26.9 | 26.0 | 15.9 | 8.91 |
| 3 | 48.6 | 47.7 | 24.4 | 26.0 | 19.0 | 8.5 |
| 4 | 39 | 35.4 | 24.0 | 25.2 | 19.4 | 19.8 |
| 5 | 46.3 | 36.0 | 23.3 | 23.3 | 19.3 | 19.2 |
| 6 | 46.8 | 35.7 | 22.8 | 22.4 | 18.7 | 18.8 |
| 7 | 47.3 | 40.2 | 22.6 | 23.5 | 17.8 | 17.6 |
| 8 | 51.9 | 41.9 | 22.2 | 23.9 | 18.6 | 17.6 |
| 9 | 48.3 | 38.8 | 23.7 | 24.1 | 18.7 | 17.9 |
| 10 | 45.1 | 40.5 | 22.7 | 24.9 | 17.6 | 16.3 |
| 11 | 46.0 | 42.7 | 22.2 | 22.7 | 18.5 | 17.9 |
| 12 | 51.9 | 45.8 | 25.0 | 22.8 | 18.6 | 17.2 |
| 13 | 50.0 | 45.5 | 24.3 | 23.1 | 19.4 | 17.9 |
| 14 | 41.2 | 36.6 | 21.5 | 22.3 | 18.5 | 18.3 |
| 15 | 37.2 | 36.0 | 21.5 | 22.5 | 17.9 | 17.9 |
| 16 | 39.4 | 37.6 | 23.3 | 21.9 | 17.9 | 18.8 |
| 17 | 38.1 | 38.6 | 20.9 | 21.7 | 17.5 | 18.6 |
| 18 | 38.5 | 35.9 | 21.1 | 21.9 | 17.8 | 17.4 |
| 19 | 40.8 | 37.0 | 21.9 | 20.0 | 18.0 | 17.6 |
| 20 | 33.3 | 30.4 | 20.6 | 21.3 | 18.7 | 17.3 |

**Colour test (mg/L PtCo)**

| Time (minute) | Sampling point | | | | | |
|---|---|---|---|---|---|---|
| | v1 | v2 | v3 | v4 | v5 | v6 |
| 1 | 397 | 233 | 168 | 158 | 82 | 77 |
| 2 | 398 | 350 | 249 | 258 | 158 | 87 |
| 3 | 422 | 362 | 241 | 245 | 195 | 85 |
| 4 | 402 | 329 | 220 | 249 | 194 | 195 |
| 5 | 400 | 338 | 221 | 229 | 185 | 200 |
| 6 | 399 | 330 | 218 | 216 | 193 | 189 |
| 7 | 417 | 349 | 213 | 226 | 187 | 179 |
| 8 | 446 | 399 | 221 | 214 | 193 | 177 |
| 9 | 420 | 355 | 218 | 216 | 196 | 176 |
| 10 | 406 | 364 | 217 | 225 | 176 | 180 |
| 11 | 397 | 365 | 218 | 208 | 189 | 188 |
| 12 | 426 | 404 | 216 | 214 | 185 | 183 |
| 13 | 473 | 430 | 225 | 221 | 190 | 190 |
| 14 | 376 | 329 | 238 | 207 | 204 | 182 |
| 15 | 343 | 342 | 202 | 207 | 184 | 182 |
| 16 | 357 | 341 | 194 | 211 | 181 | 188 |
| 17 | 364 | 345 | 212 | 205 | 182 | 181 |
| 18 | 352 | 347 | 203 | 222 | 186 | 182 |
| 19 | 363 | 347 | 210 | 207 | 199 | 162 |
| 20 | 299 | 290 | 208 | 205 | 206 | 183 |

**Iron concentration test (mg/L Fe)**

| Time (minute) | Sampling point | | | | | |
|---|---|---|---|---|---|---|
| | v1 | v2 | v3 | v4 | v5 | v6 |
| 1 | 3.10 | 2.19 | 1.10 | 1.13 | 0.35 | 0.52 |
| 2 | 1.95 | 2.86 | 1.81 | 2.02 | 1.11 | 0.51 |
| 3 | 2.60 | 1.59 | 1.78 | 1.98 | 1.32 | 0.70 |
| 4 | 2.70 | 2.11 | 1.50 | 1.85 | 1.47 | 1.19 |
| 5 | 2.90 | 2.30 | 1.57 | 1.71 | 1.42 | 1.43 |
| 6 | 1.55 | 2.30 | 1.55 | 1.82 | 1.43 | 1.35 |
| 7 | 1.80 | 1.60 | 1.62 | 1.75 | 1.26 | 1.37 |
| 8 | 2.05 | 1.25 | 1.77 | 1.75 | 1.40 | 1.43 |
| 9 | 2.85 | 2.05 | 1.80 | 1.78 | 1.51 | 1.33 |
| 10 | 2.55 | 1.60 | 1.76 | 1.58 | 1.37 | 1.33 |
| 11 | 2.15 | 2.20 | 1.75 | 1.76 | 1.32 | 1.38 |
| 12 | 1.50 | 3.20 | 1.81 | 1.76 | 1.39 | 1.27 |
| 13 | 2.50 | 2.60 | 1.94 | 1.82 | 1.21 | 1.3 |
| 14 | 2.60 | 1.70 | 1.79 | 1.78 | 1.34 | 1.34 |
| 15 | 2.10 | 1.85 | 1.75 | 1.73 | 1.16 | 1.41 |
| 16 | 1.45 | 2.75 | 1.75 | 1.62 | 1.30 | 1.39 |
| 17 | 1.60 | 1.55 | 1.80 | 1.59 | 1.17 | 1.37 |
| 18 | 1.45 | 2.6 | 1.72 | 1.68 | 1.26 | 1.27 |
| 19 | 1.35 | 2.80 | 1.70 | 1.58 | 1.19 | 1.29 |
| 20 | 1.20 | 1.45 | 1.78 | 1.78 | 1.24 | 1.41 |

**Run 2**

Initial iron concentration = 3.55 mg/L
Initial turbidity = 51.5 NTU
Initial colour = 428 PtCo
Average Flow rate = 380 mL/s

***Turbidity test (NTU)***

| Time (minute) | Sampling point | | | | | |
|---|---|---|---|---|---|---|
| | v1 | v2 | v3 | v4 | v5 | v6 |
| 0.5 | 31.2 | 22.3 | 17.2 | 14.4 | 13.1 | 12.3 |
| 1 | 29 | 20.6 | 15 | 11.1 | 9.82 | 11 |
| 1.5 | 30.6 | 21.1 | 14.8 | 15.2 | 12.8 | 9.92 |
| 2 | 29.7 | 19.7 | 16.4 | 18.6 | 11.8 | 12.5 |
| 2.5 | 29.1 | 19.6 | 18 | 17.5 | 12.9 | 12.9 |
| 3 | 29 | 19.2 | 16.4 | 16.7 | 12.8 | 12.3 |
| 3.5 | 27.8 | 18.8 | 17.3 | 19.2 | 12.7 | 12.2 |
| 4 | 28.4 | 19.1 | 17.3 | 16.7 | 12.8 | 12 |
| 4.5 | 30.7 | 19.2 | 16.6 | 12.3 | 12.1 | 10.5 |
| 5 | 30.5 | 18.1 | 17.7 | 15.1 | 11.1 | 11.6 |
| 6 | 34 | 16.8 | 16.7 | 15.6 | 12.1 | 12 |
| 7 | 33.2 | 17.9 | 17.5 | 13.4 | 11.3 | 11.3 |
| 8 | 30.8 | 17.5 | 16.5 | 13.6 | 11 | 11.2 |
| 9 | 35.6 | 17.3 | 17.2 | 14.6 | 12.2 | 10.9 |
| 10 | 35.9 | 18.4 | 16 | 13.1 | 11.9 | 11.1 |
| 11 | 34.9 | 16.7 | 16.4 | 16.6 | 11.3 | 10.3 |
| 12 | 29.5 | 16.4 | 16.3 | 11.6 | 11.8 | 11.5 |
| 13 | 25.8 | 14.5 | 15.5 | 11.8 | 13 | 10.9 |
| 14 | 28.4 | 15.7 | 16.4 | 15.9 | 13.1 | 10.4 |
| 15 | 22 | 14.6 | 13.3 | 11.2 | 12.9 | 9.82 |
| 16 | 17 | 16.8 | 13.5 | 12.4 | 11.5 | 10.6 |
| 17 | 17 | 14.9 | 13.9 | 12.2 | 11.7 | 10.5 |
| 18 | | | | 12.5 | 10.8 | 10.6 |
| 19 | | | | 12.2 | 10.1 | 9.78 |
| 20 | | | | 11.6 | 9.96 | 10.3 |

**Colour test (mg/L PtCo)**

| Time (minute) | Sampling point | | | | | |
|---|---|---|---|---|---|---|
| | v1 | v2 | v3 | v4 | v5 | v6 |
| 0.5 | 307 | 222 | 184 | 161 | 142 | 133 |
| 1 | 281 | 210 | 169 | 139 | 124 | 124 |
| 1.5 | 299 | 209 | 155 | 159 | 136 | 118 |
| 2 | 294 | 203 | 183 | 199 | 129 | 134 |
| 2.5 | 293 | 203 | 193 | 189 | 135 | 138 |
| 3 | 280 | 203 | 182 | 180 | 150 | 131 |
| 3.5 | 273 | 201 | 185 | 195 | 134 | 129 |
| 4 | 278 | 202 | 183 | 172 | 140 | 125 |
| 4.5 | 295 | 194 | 172 | 132 | 130 | 121 |
| 5 | 289 | 189 | 178 | 171 | 126 | 123 |
| 6 | 307 | 187 | 178 | 167 | 129 | 122 |
| 7 | 308 | 181 | 176 | 146 | 129 | 126 |
| 8 | 291 | 182 | 177 | 148 | 123 | 128 |
| 9 | 337 | 182 | 177 | 166 | 131 | 114 |
| 10 | 341 | 191 | 177 | 140 | 130 | 118 |
| 11 | 344 | 190 | 170 | 173 | 125 | 130 |
| 12 | 300 | 172 | 173 | 133 | 127 | 128 |
| 13 | 258 | 166 | 159 | 125 | 132 | 122 |
| 14 | 277 | 165 | 166 | 160 | 147 | 114 |
| 15 | 233 | 164 | 145 | 130 | 134 | 121 |
| 16 | 183 | 181 | 146 | 135 | 130 | 118 |
| 17 | 185 | 162 | 153 | 129 | 135 | 110 |
| 18 | | | | 141 | 119 | 113 |
| 19 | | | | 141 | 118 | 113 |
| 20 | | | | 127 | 118 | 109 |

**Iron concentration test (mg/L Fe)**

| Time (minute) | Sampling point | | | | | |
|---|---|---|---|---|---|---|
| | v1 | v2 | v3 | v4 | v5 | v6 |
| 0.5 | 3.1 | 1.56 | 1.34 | 1.36 | 0.84 | 0.63 |
| 1 | 2.83 | 1.91 | 1.36 | 0.81 | 0.85 | 1 |
| 1.5 | 2.54 | 1.76 | 1.27 | 1.44 | 1.01 | 0.76 |
| 2 | 2.75 | 1.44 | 1.3 | 1.46 | 0.85 | 1.06 |
| 2.5 | 2.76 | 1.75 | 1.59 | 1.53 | 1.09 | 1.09 |
| 3 | 2.15 | 1.42 | 1.32 | 1.37 | 1.03 | 0.94 |
| 3.5 | 2.72 | 1.59 | 1.53 | 1.71 | 1.08 | 0.97 |
| 4 | 2.7 | 1.56 | 1.48 | 1.53 | 1.01 | 1.05 |
| 4.5 | 2.5 | 1.46 | 1.22 | 1.23 | 0.91 | 0.7 |
| 5 | 2.86 | 1.61 | 1.49 | 1.46 | 0.98 | 1.04 |
| 6 | 2.89 | 1.29 | 1.41 | 1.31 | 0.92 | 1.02 |
| 7 | 2.5 | 1.4 | 1.37 | 1.2 | 0.94 | 0.92 |
| 8 | 2.95 | 1.53 | 1.53 | 1.19 | 1 | 0.98 |
| 9 | 2.8 | 1.58 | 1.53 | 1.23 | 0.94 | 0.9 |
| 10 | 2.83 | 1.47 | 1.5 | 0.97 | 0.95 | 0.94 |
| 11 | 2.72 | 1.3 | 1.17 | 1.19 | 0.83 | 0.67 |
| 12 | 2.6 | 1.27 | 1.15 | 1.13 | 0.9 | 0.87 |
| 13 | 2.68 | 1.28 | 1.28 | 0.98 | 0.98 | 0.84 |
| 14 | 2.73 | 1.49 | 1.27 | 0.98 | 1.01 | 0.88 |
| 15 | 2.14 | 1.4 | 1.17 | 0.78 | 1.03 | 0.71 |
| 16 | 1.83 | 1.35 | 1.14 | 1.07 | 0.97 | 0.92 |
| 17 | 1.82 | 1.43 | 1.28 | 1.11 | 1.08 | 0.96 |
| 18 | | | | 1.05 | 0.85 | 0.94 |
| 19 | | | | 0.92 | 0.89 | 0.86 |
| 20 | | | | 1.01 | 0.88 | 0.87 |

**Run 3**

Initial iron concentration = 5.75 mg/L
Initial turbidity = 31.9 NTU
Initial colour = 395 PtCo
Average Flow rate = 143 mL/s

**Turbidity test (NTU)**

| Time(minute) | Sampling point V6 | Time(minute) | Sampling point V6 |
|---|---|---|---|
| 1 | 12.1 | 11 | 8.06 |
| 2 | 7.96 | 12 | 7.73 |
| 3 | 7.10 | 13 | 7.77 |
| 4 | 7.60 | 14 | 8.09 |
| 5 | 7.15 | 15 | 8.09 |
| 6 | 6.99 | 16 | 7.49 |
| 7 | 7.07 | 17 | 7.90 |
| 8 | 7.06 | 18 | 7.40 |
| 9 | 7.47 | 19 | 7.89 |
| 10 | 7.44 | 20 | 7.60 |

**Colour test (mg/L PtCo)**

| Time(minute) | Sampling point V6 | Time(minute) | Sampling point V6 |
|---|---|---|---|
| 1 | 132 | 11 | 94 |
| 2 | 106 | 12 | 96 |
| 3 | 96 | 13 | 93 |
| 4 | 89 | 14 | 95 |
| 5 | 86 | 15 | 90 |
| 6 | 87 | 16 | 91 |
| 7 | 86 | 17 | 93 |
| 8 | 82 | 18 | 86 |
| 9 | 82 | 19 | 89 |
| 10 | 84 | 20 | 83 |

**Iron concentration test (mg/L Fe)**

| Time(minute) | Sampling point V6 | Time(minute) | Sampling point V6 |
|---|---|---|---|
| 1 | 1.99 | 11 | 1.53 |
| 2 | 1.59 | 12 | 1.61 |
| 3 | 1.41 | 13 | 1.58 |
| 4 | 1.50 | 14 | 1.59 |
| 5 | 1.35 | 15 | 1.59 |
| 6 | 1.33 | 16 | 1.52 |
| 7 | 1.32 | 17 | 1.56 |
| 8 | 1.40 | 18 | 1.50 |
| 9 | 1.43 | 19 | 1.57 |
| 10 | 1.50 | 20 | 1.53 |

**Run 4**

Initial iron concentration = 5.75 mg/L
Initial turbidity = 31.9 NTU
Initial colour = 395 PtCo

| Minute | Colour | Turbidity | Iron | Minute | Colour | Turbidity | Iron |
|---|---|---|---|---|---|---|---|
| 1 | 165 | 11.1 | 1.69 | 71 | 11 | 0.93 | 0.08 |
| 2 | 153 | 11.3 | 1.81 | 72 | 13 | 0.94 | 0.08 |
| 3 | 145 | 11.5 | 1.60 | 73 | 12 | 0.97 | 0.07 |
| 4 | 142 | 10.0 | 1.51 | 74 | 13 | 0.83 | 0.08 |
| 5 | 148 | 9.01 | 1.44 | 75 | 8 | 0.84 | 0.07 |
| 6 | 109 | 9.01 | 1.41 | 76 | 7 | 0.91 | 0.09 |
| 7 | 105 | 8.66 | 1.25 | 77 | 9 | 0.92 | 0.08 |
| 8 | 114 | 8.60 | 1.04 | 78 | 8 | 0.87 | 0.09 |
| 9 | 103 | 8.24 | 1.16 | 79 | 7 | 0.89 | 0.06 |
| 10 | 96 | 7.88 | 1.05 | 80 | 6 | 0.83 | 0.04 |
| 11 | 105 | 7.58 | 1.20 | 81 | 6 | 0.84 | 0.08 |
| 12 | 87 | 7.5 | 1.16 | 82 | 6 | 0.83 | 0.08 |
| 13 | 104 | 7.41 | 1.20 | 83 | 7 | 0.82 | 0.07 |
| 14 | 101 | 7.16 | 1.18 | 84 | 5 | 0.86 | 0.07 |
| 15 | 84 | 7.5 | 1.08 | 85 | 6 | 0.96 | 0.06 |
| 16 | 102 | 6.9 | 1.01 | 86 | 7 | 0.82 | 0.07 |
| 17 | 81 | 6.87 | 1.01 | 87 | 7 | 0.87 | 0.08 |
| 18 | 74 | 6.79 | 0.96 | 88 | 7 | 0.83 | 0.07 |
| 19 | 86 | 6.77 | 0.99 | 89 | 6 | 0.89 | 0.04 |
| 20 | 81 | 6.62 | 0.94 | 90 | 5 | 0.78 | 0.06 |
| 21 | 74 | 6.45 | 0.79 | 91 | 6 | 0.81 | 0.07 |
| 22 | 87 | 6.51 | 0.78 | 92 | 5 | 0.82 | 0.05 |
| 23 | 77 | 6.45 | 0.82 | 93 | 5 | 0.29 | 0.04 |
| 24 | 79 | 6.31 | 0.72 | 94 | 6 | 0.76 | 0.06 |
| 25 | 86 | 6.11 | 0.7 | 95 | 4 | 0.77 | 0.05 |
| 26 | 63 | 6.15 | 0.45 | 96 | 5 | 0.74 | 0.05 |
| 27 | 61 | 5.57 | 0.48 | 97 | 5 | 0.69 | 0.07 |
| 28 | 40 | 5.43 | 0.32 | 98 | 6 | 0.70 | 0.07 |
| 29 | 63 | 4.83 | 0.30 | 99 | 4 | 0.68 | 0.06 |
| 30 | 36 | 4.05 | 0.33 | 100 | 5 | 0.67 | 0.03 |
| 31 | 36 | 3.65 | 0.32 | 101 | 5 | 0.63 | 0.05 |
| 32 | 24 | 3.97 | 0.30 | 102 | 5 | 0.66 | 0.05 |
| 33 | 35 | 2.09 | 0.35 | 103 | 3 | 0.63 | 0.04 |

| 34 | 23 | 1.96 | 0.33 | 104 | 4 | 0.64 | 0.06 |
|---|---|---|---|---|---|---|---|
| 35 | 22 | 1.76 | 0.23 | 105 | 2 | 0.64 | 0.05 |
| 36 | 25 | 1.46 | 0.36 | 106 | 3 | 0.62 | 0.05 |
| 37 | 21 | 1.43 | 0.45 | 107 | 3 | 0.59 | 0.07 |
| 38 | 23 | 1.39 | 0.39 | 108 | 3 | 0.61 | 0.05 |
| 39 | 22 | 1.47 | 0.2 | 109 | 1 | 0.58 | 0.06 |
| 40 | 24 | 1.45 | 0.19 | 110 | 2 | 0.55 | 0.05 |
| 41 | 25 | 1.44 | 0.19 | 111 | 2 | 0.55 | 0.06 |
| 42 | 22 | 1.42 | 0.18 | 112 | 2 | 0.54 | 0.05 |
| 43 | 23 | 1.43 | 0.15 | 113 | 1 | 0.56 | 0.05 |
| 44 | 22 | 1.41 | 0.14 | 114 | 2 | 0.55 | 0.07 |
| 45 | 18 | 1.36 | 0.18 | 115 | 3 | 0.54 | 0.05 |
| 46 | 17 | 1.38 | 0.15 | 116 | 1 | 0.55 | 0.05 |
| 47 | 18 | 1.41 | 0.14 | 117 | 2 | 0.51 | 0.05 |
| 48 | 18 | 1.35 | 0.15 | 118 | 1 | 0.53 | 0.07 |
| 49 | 19 | 1.36 | 0.12 | 119 | 1 | 0.59 | 0.07 |
| 50 | 16 | 1.35 | 0.12 | 120 | 3 | 0.60 | 0.06 |
| 51 | 17 | 1.28 | 0.12 | 121 | 2 | 0.55 | 0.05 |
| 52 | 13 | 1.31 | 0.15 | 122 | 2 | 0.53 | 0.07 |
| 53 | 14 | 1.30 | 0.14 | 123 | 1 | 0.49 | 0.05 |
| 54 | 14 | 1.30 | 0.13 | 124 | -1 | 0.47 | 0.07 |
| 55 | 14 | 1.24 | 0.15 | 125 | 2 | 0.48 | 0.06 |
| 56 | 12 | 1.25 | 0.13 | 126 | 1 | 0.45 | 0.05 |
| 57 | 13 | 1.23 | 0.11 | 127 | 1 | 0.44 | 0.06 |
| 58 | 14 | 1.22 | 0.11 | 128 | -1 | 0.47 | 0.05 |
| 59 | 12 | 1.24 | 0.12 | 129 | 2 | 0.48 | 0.05 |
| 60 | 11 | 1.22 | 0.09 | 130 | -2 | 0.38 | 0.04 |
| 61 | 10 | 1.17 | 0.08 | 131 | 1 | 0.35 | 0.06 |
| 62 | 11 | 1.16 | 0.09 | 132 | -2 | 0.37 | 0.05 |
| 63 | 9 | 1.16 | 0.09 | 133 | -1 | 0.35 | 0.04 |
| 64 | 12 | 1.11 | 0.06 | 134 | 1 | 0.36 | 0.06 |
| 65 | 13 | 1.10 | 0.04 | 135 | 1 | 0.36 | 0.05 |
| 66 | 12 | 1.07 | 0.08 | 136 | -2 | 0.33 | 0.06 |
| 67 | 12 | 1.09 | 0.08 | 137 | 1 | 0.31 | 0.05 |
| 68 | 10 | 1.07 | 0.07 | 138 | -1 | 0.29 | 0.06 |
| 69 | 9 | 0.97 | 0.08 | 139 | 1 | 0.30 | 0.05 |
| 70 | 9 | 0.98 | 0.07 | | | | |

**Run 5**

Initial iron concentration = 21.20 mg/L
Initial turbidity = 65.6NTU
Initial colour = 395 PtCo

| Minute | Colour | Turbidity | Iron | Minute | Colour | Turbidity | Iron |
|---|---|---|---|---|---|---|---|
| 1 | 180 | 19.84 | 1.89 | 1 | 10 | 1.01 | 0.14 |
| 2 | 143 | 18.88 | 1.74 | 2 | 10 | 0.98 | 0.17 |
| 3 | 125 | 13.92 | 1.60 | 3 | 9 | 0.95 | 0.11 |
| 4 | 117 | 12.84 | 1.64 | 4 | 8 | 0.93 | 0.14 |
| 5 | 94 | 9.34 | 1.59 | 5 | 7 | 0.93 | 0.09 |
| 6 | 88 | 9.37 | 1.65 | 6 | 8 | 0.87 | 0.11 |
| 7 | 84 | 7.31 | 1.48 | 7 | 7 | 0.85 | 0.07 |
| 8 | 76 | 7.42 | 1.44 | 8 | 6 | 0.82 | 0.07 |
| 9 | 83 | 6.93 | 1.33 | 9 | 6 | 0.76 | 0.08 |
| 10 | 70 | 6.50 | 1.29 | 10 | 7 | 0.73 | 0.08 |
| 11 | 68 | 6.46 | 1.30 | 11 | 5 | 0.75 | 0.08 |
| 12 | 66 | 6.42 | 1.26 | 12 | 6 | 0.77 | 0.07 |
| 13 | 69 | 5.33 | 1.16 | 13 | 4 | 0.72 | 0.08 |
| 14 | 47 | 5.21 | 1.09 | 14 | 5 | 0.70 | 0.07 |
| 15 | 42 | 4.96 | 0.96 | 15 | 5 | 0.69 | 0.08 |
| 16 | 45 | 4.72 | 0.82 | 16 | 6 | 0.65 | 0.08 |
| 17 | 35 | 3.38 | 0.80 | 17 | 4 | 0.62 | 0.07 |
| 18 | 37 | 3.26 | 0.76 | 18 | 4 | 0.59 | 0.08 |
| 19 | 38 | 3.21 | 0.60 | 19 | 2 | 0.60 | 0.07 |
| 20 | 33 | 3.17 | 0.56 | 20 | 3 | 0.55 | 0.09 |
| 21 | 22 | 1.40 | 0.39 | 21 | 3 | 0.53 | 0.08 |
| 22 | 23 | 1.36 | 0.40 | 22 | 3 | 0.49 | 0.07 |
| 23 | 21 | 1.60 | 0.37 | 23 | 1 | 0.47 | 0.04 |
| 24 | 19 | 1.17 | 0.26 | 24 | 2 | 0.48 | 0.06 |
| 25 | 17 | 1.19 | 0.27 | 25 | 2 | 0.45 | 0.07 |
| 26 | 17 | 1.15 | 0.23 | 26 | 2 | 0.44 | 0.05 |
| 27 | 18 | 1.14 | 0.23 | 27 | 1 | 0.39 | 0.04 |
| 28 | 17 | 1.16 | 0.26 | 28 | 2 | 0.40 | 0.06 |
| 29 | 16 | 1.12 | 0.18 | 29 | -1 | 0.36 | 0.05 |
| 30 | 18 | 1.09 | 0.18 | 30 | 1 | 0.37 | 0.05 |
| 31 | 15 | 1.06 | 0.17 | 31 | 2 | 0.35 | 0.07 |
| 32 | 13 | 1.05 | 0.21 | 32 | 1 | 0.38 | 0.06 |
| 33 | 17 | 1.03 | 0.17 | 33 | -1 | 0.35 | 0.03 |
| 34 | 12 | 1.04 | 0.16 | 34 | 2 | 0.31 | 0.05 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 35 | 12 | 1.04 | 0.14 | 35 | 1 | 0.28 | 0.04 |
| 36 | 13 | 1.01 | 0.11 | 36 | 1 | 0.32 | 0.05 |
| 37 | 11 | 1.02 | 0.11 | 37 | -1 | 0.27 | 0.04 |

**Run 6**

Initial iron concentration = 2.07 mg/L
Initial turbidity = 7.92 NTU
Initial colour = 111 PtCo

**Turbidity test (NTU)**

| time (minute) | sampling point | | | | | |
|---|---|---|---|---|---|---|
| | v1 | v2 | v3 | v4 | v5 | v6 |
| 1 | 7.18 | 5.28 | 5.00 | 5.07 | 4.75 | 4.63 |
| 2 | 6.46 | 4.06 | 3.85 | 3.9 | 4.05 | 3.88 |
| 3 | 5.88 | 3.43 | 2.29 | 3.58 | 3.2 | 3.17 |
| 4 | 5.21 | 3.33 | 3.01 | 2.65 | 3.09 | 3.05 |
| 5 | 5.18 | 3.02 | 2.98 | 2.53 | 2.55 | 2.55 |
| 6 | 5.07 | 2.87 | 2.81 | 2.61 | 2.54 | 2.54 |
| 7 | 4.93 | 2.99 | 2.83 | 2.49 | 2.6 | 2.46 |
| 8 | 4.77 | 3.01 | 2.78 | 2.5 | 2.46 | 2.38 |
| 9 | 4.72 | 2.88 | 2.63 | 2.41 | 2.35 | 2.39 |
| 10 | 4.61 | 2.79 | 2.77 | 2.34 | 2.35 | 2.31 |
| 11 | 4.44 | 2.73 | 2.74 | 2.39 | 2.33 | 2.25 |
| 12 | 4.48 | 2.78 | 2.6 | 2.28 | 2.36 | 2.23 |
| 13 | 4.55 | 2.57 | 2.46 | 2.17 | 2.27 | 2.21 |
| 14 | 4.54 | 2.71 | 2.51 | 2.23 | 2.21 | 2.22 |

**Colour test (mg/L PtCo)**

| time (minute) | sampling point | | | | | |
|---|---|---|---|---|---|---|
| | v1 | v2 | v3 | v4 | v5 | v6 |
| 1 | 100 | 83 | 70 | 84 | 82 | 80 |
| 2 | 81 | 61 | 58 | 76 | 55 | 64 |
| 3 | 79 | 52 | 45 | 67 | 43 | 44 |
| 4 | 78 | 55 | 41 | 43 | 50 | 43 |
| 5 | 79 | 39 | 51 | 32 | 38 | 35 |
| 6 | 75 | 39 | 55 | 46 | 38 | 31 |
| 7 | 76 | 40 | 51 | 33 | 43 | 29 |
| 8 | 71 | 43 | 38 | 33 | 35 | 31 |
| 9 | 65 | 40 | 37 | 42 | 33 | 35 |
| 10 | 62 | 37 | 45 | 32 | 36 | 30 |
| 11 | 64 | 35 | 34 | 29 | 38 | 34 |
| 12 | 61 | 36 | 32 | 33 | 30 | 33 |
| 13 | 69 | 35 | 38 | 30 | 27 | 25 |
| 14 | 72 | 43 | 39 | 32 | 28 | 26 |

**Iron concentration test (mg/L Fe)**

| time (minute) | Sampling point | | | | | |
|---|---|---|---|---|---|---|
| | v1 | v2 | v3 | v4 | v5 | v6 |
| 1 | 1.51 | 1.22 | 1.20 | 1.16 | 1.13 | 1.04 |
| 2 | 1.40 | 0.95 | 0.89 | 0.81 | 0.89 | 0.88 |
| 3 | 1.32 | 0.78 | 0.76 | 0.71 | 0.69 | 0.70 |
| 4 | 1.19 | 0.69 | 0.70 | 0.63 | 0.66 | 0.64 |
| 5 | 1.15 | 0.68 | 0.59 | 0.54 | 0.53 | 0.51 |
| 6 | 1.15 | 0.68 | 0.61 | 0.48 | 0.51 | 0.49 |
| 7 | 1.10 | 0.65 | 0.56 | 0.51 | 0.49 | 0.45 |
| 8 | 1.1 | 0.64 | 0.59 | 0.50 | 0.51 | 0.46 |
| 9 | 1.04 | 0.61 | 0.55 | 0.49 | 0.47 | 0.45 |
| 10 | 1.02 | 0.63 | 0.55 | 0.50 | 0.47 | 0.43 |
| 11 | 1.00 | 0.57 | 0.5 | 0.48 | 0.46 | 0.42 |
| 12 | 1.00 | 0.58 | 0.53 | 0.51 | 0.45 | 0.42 |
| 13 | 0.93 | 0.55 | 0.52 | 0.46 | 0.43 | 0.41 |
| 14 | 1.01 | 0.51 | 0.53 | 0.45 | 0.43 | 0.38 |

## Appendix C

### Run 1

### Data analysis of turbidity test

t-Test: Two-Sample Assuming Equal Variances

| | *V1* | *V2* |
|---|---|---|
| Mean | 44.255 | 38.275 |
| Variance | 28.99629 | 26.88513 |
| Observations | 20 | 20 |
| Pooled Variance | 27.94071 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | 3.577523 | |
| P(T<=t) one-tail | 0.000483 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 0.000967 | |
| t Critical two-tail | 2.024394 | |

Since t Stat > 2.024, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V1 and sampling point v2 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V3* | *V4* |
|---|---|---|
| Mean | 22.66 | 22.8 |
| Variance | 3.440421 | 4.605263 |
| Observations | 20 | 20 |
| Pooled Variance | 4.022842 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | -0.22073 | |
| P(T<=t) one-tail | 0.413242 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 0.826484 | |
| t Critical two-tail | 2.024394 | |

Since -2.024< t Stat < 2.024, therefore accept Ho=0, and conclude that there is NO significant difference between colour at sampling point v3 and v4 T2 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V5* | *V6* |
|---|---|---|
| Mean | 17.773 | 16.5765 |
| Variance | 6.321317 | 12.80323 |
| Observations | 20 | 20 |
| Pooled Variance | 9.562276 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | 1.223579 | |
| P(T<=t) one-tail | 0.114322 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 0.228644 | |
| t Critical two-tail | 2.024394 | |

Since -2.024< t Stat < 2.024, therefore accept Ho=0, and conclude that there is NO significant difference between colour at sampling point v5 and v6 T2 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V1* | *V6* |
|---|---|---|
| Mean | 44.255 | 16.5765 |
| Variance | 28.99629 | 12.80323 |
| Observations | 20 | 20 |
| Pooled Variance | 20.89976 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | 19.14573 | |
| P(T<=t) one-tail | 2.05E-21 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 4.1E-21 | |
| t Critical two-tail | 2.024394 | |

Since t Stat > 2.024, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V1 and sampling point v6 at 5% level of significance.

## Data analysis of colour test

t-Test: Two-Sample Assuming Equal Variances

| | *V1* | *V2* |
|---|---|---|
| Mean | 392.85 | 347.45 |
| Variance | 1535.713 | 1635.839 |
| Observations | 20 | 20 |
| Pooled Variance | 1585.776 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | 3.605246 | |
| P(T<=t) one-tail | 0.000447 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 0.000893 | |
| t Critical two-tail | 2.024394 | |

Since t Stat > 2.024, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V1 and sampling point v2 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V3* | *V4* |
|---|---|---|
| Mean | 215.6 | 217.15 |
| Variance | 296.4632 | 422.3447 |
| Observations | 20 | 20 |
| Pooled Variance | 359.4039 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | -0.25855 | |
| P(T<=t) one-tail | 0.39869 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 0.79738 | |
| t Critical two-tail | 2.024394 | |

Since -2.024 < t Stat < 2.024, therefore accept Ho=0, and conclude that there is NO significant difference between colour at sampling point v3 and v4 T2 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V5* | *V6* |
|---|---|---|
| Mean | 183.25 | 168.3 |
| Variance | 676.7237 | 1413.695 |
| Observations | 20 | 20 |
| Pooled Variance | 1045.209 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | 1.46231 | |
| P(T<=t) one-tail | 0.075939 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 0.151878 | |
| t Critical two-tail | 2.024394 | |

Since -2.0244 < t Stat < 2.0244, therefore accept Ho=0, and conclude that there is NO significant difference between colour at sampling point v5 and v6 T2 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V1* | *V6* |
|---|---|---|
| Mean | 392.85 | 168.3 |
| Variance | 1535.713 | 1413.695 |
| Observations | 20 | 20 |
| Pooled Variance | 1474.704 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | 18.49101 | |
| P(T<=t) one-tail | 6.79E-21 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 1.36E-20 | |
| t Critical two-tail | 2.024394 | |

Since t Stat > 2.024, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V1 and sampling point v6 at 5% level of significance.

## Data analysis of iron concentration test

t-Test: Two-Sample Assuming Equal Variances

| | *V1* | *V2* |
|---|---|---|
| Mean | 2.0975 | 2.1275 |
| Variance | 0.351178 | 0.30083 |
| Observations | 20 | 20 |
| Pooled Variance | 0.326004 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | -0.16615 | |
| P(T<=t) one-tail | 0.434458 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 0.868917 | |
| t Critical two-tail | 2.024394 | |

Since -2.0244< t Stat < 2.0244, therefore accept Ho=0, and conclude that there is NO significant difference between colour at sampling point v1 and v2 T2 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V3* | *V4* |
|---|---|---|
| Mean | 1.7025 | 1.7235 |
| Variance | 0.030778 | 0.03295 |
| Observations | 20 | 20 |
| Pooled Variance | 0.031864 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | -0.37202 | |
| P(T<=t) one-tail | 0.355971 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 0.711943 | |
| t Critical two-tail | 2.024394 | |

Since -0.37202< t Stat < 0.37202, therefore accept Ho=0, and conclude that there is NO significant difference between colour at sampling point v3 and v4 T2 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V5* | *V6* |
|---|---|---|
| **Mean** | 1.261 | 1.2295 |
| Variance | 0.057967 | 0.083963 |
| Observations | 20 | 20 |
| Pooled Variance | 0.070965 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | 0.373928 | |
| P(T<=t) one-tail | 0.355268 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 0.710536 | |
| t Critical two-tail | 2.024394 | |

Since -2.024< t Stat < 2.024, therefore accept Ho=0, and conclude that there is NO significant difference between colour at sampling point v5 and v6 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V1* | *V6* |
|---|---|---|
| **Mean** | 2.0975 | 1.2295 |
| Variance | 0.351178 | 0.083963 |
| Observations | 20 | 20 |
| Pooled Variance | 0.21757 | |
| Hypothesized Mean Difference | 0 | |
| df | 38 | |
| t Stat | 5.884641 | |
| P(T<=t) one-tail | 4.1E-07 | |
| t Critical one-tail | 1.685954 | |
| P(T<=t) two-tail | 8.2E-07 | |
| t Critical two-tail | 2.024394 | |

Since t Stat > 2.024, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V1 and sampling point v6 at 5% level of significance.

## Run 2

## Data analysis of turbidity test

t-Test: Two-Sample Assuming Equal Variances

| | *V2* | *V3* |
|---|---|---|
| Mean | 17.96364 | 16.17727 |
| Variance | 4.370043 | 1.770411 |
| Observations | 22 | 22 |
| Pooled Variance | 3.070227 | |
| Hypothesized Mean Difference | 0 | |
| df | 42 | |
| t Stat | 3.381279 | |
| P(T<=t) one-tail | 0.000785 | |
| t Critical one-tail | 1.681952 | |
| P(T<=t) two-tail | 0.00157 | |
| t Critical two-tail | 2.018082 | |

Since t Stat > 2.0181, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V2 and sampling point v3 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V5* | *V6* |
|---|---|---|
| Mean | 11.8632 | 11.1368 |
| Variance | 1.009423 | 0.799556 |
| Observations | 25 | 25 |
| Pooled Variance | 0.904489 | |
| Hypothesized Mean Difference | 0 | |
| df | 48 | |
| t Stat | 2.700406 | |
| P(T<=t) one-tail | 0.004769 | |
| t Critical one-tail | 1.677224 | |
| P(T<=t) two-tail | 0.009538 | |
| t Critical two-tail | 2.010635 | |

Since t Stat > 2.0106, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V5 and sampling point v6 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V1* | *V6* |
|---|---|---|
| **Mean** | 29.09545 | 11.26091 |
| Variance | 25.44522 | 0.762913 |
| Observations | 22 | 22 |
| Pooled Variance | 13.10406 | |
| Hypothesized Mean Difference | 0 | |
| df | 42 | |
| t Stat | 16.34012 | |
| P(T<=t) one-tail | 4.13E-20 | |
| t Critical one-tail | 1.681952 | |
| P(T<=t) two-tail | 8.26E-20 | |
| t Critical two-tail | 2.018082 | |

Since t Stat > 2.0181, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V1 and sampling point v6 at 5% level of significance.

## Data analysis of colour test

t-Test: Two-Sample Assuming Equal Variances

| | *V2* | *V3* |
|---|---|---|
| Mean | 189.0455 | 171.8636 |
| Variance | 278.0455 | 168.2186 |
| Observations | 22 | 22 |
| Pooled Variance | 223.132 | |
| Hypothesized Mean Difference | 0 | |
| df | 42 | |
| t Stat | 3.814912 | |
| P(T<=t) one-tail | 0.00022 | |
| t Critical one-tail | 1.681952 | |
| P(T<=t) two-tail | 0.000441 | |
| t Critical two-tail | 2.018082 | |

Since t Stat > 2.0181, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V2 and sampling point v3 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V5* | *V6* |
|---|---|---|
| Mean | 130.92 | 122.48 |
| Variance | 65.91 | 61.01 |
| Observations | 25 | 25 |
| Pooled Variance | 63.46 | |
| Hypothesized Mean Difference | 0 | |
| df | 48 | |
| t Stat | 3.745824 | |
| P(T<=t) one-tail | 0.000241 | |
| t Critical one-tail | 1.677224 | |
| P(T<=t) two-tail | 0.000482 | |
| t Critical two-tail | 2.010635 | |

Since t Stat > 2.0106, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V5 and sampling point v6 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V1* | *V6* |
|---|---|---|
| Mean | 284.2273 | 123.9545 |
| Variance | 1697.994 | 50.23593 |
| Observations | 22 | 22 |
| Pooled Variance | 874.1147 | |
| Hypothesized Mean Difference | 0 | |
| df | 42 | |
| t Stat | 17.97926 | |
| P(T<=t) one-tail | 1.22E-21 | |
| t Critical one-tail | 1.681952 | |
| P(T<=t) two-tail | 2.44E-21 | |
| t Critical two-tail | 2.018082 | |

Since t Stat > 2.0181, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V1 and sampling point v6 at 5% level of significance.

## Data analysis of iron concentration test

t-Test: Two-Sample Assuming Equal Variances

| | *V2* | *V3* |
|---|---|---|
| Mean | 1.493182 | 1.35 |
| Variance | 0.027489 | 0.019514 |
| Observations | 22 | 22 |
| Pooled Variance | 0.023502 | |
| Hypothesized Mean Difference | 0 | |
| df | 42 | |
| t Stat | 3.097657 | |
| P(T<=t) one-tail | 0.001736 | |
| t Critical one-tail | 1.681952 | |
| P(T<=t) two-tail | 0.003471 | |
| t Critical two-tail | 2.018082 | |

Since t Stat > 2.0181, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V2 and sampling point v3 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V5* | *V6* |
|---|---|---|
| Mean | 0.9528 | 0.9008 |
| Variance | 0.006321 | 0.015733 |
| Observations | 25 | 25 |
| Pooled Variance | 0.011027 | |
| Hypothesized Mean Difference | 0 | |
| df | 48 | |
| t Stat | 1.750786 | |
| P(T<=t) one-tail | 0.043186 | |
| t Critical one-tail | 1.677224 | |
| P(T<=t) two-tail | 0.086372 | |
| t Critical two-tail | 2.010635 | |

Since t Stat > 2.0106, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V5 and sampling point v6 at 5% level of significance.

t-Test: Two-Sample Assuming Equal Variances

| | *V1* | *V6* |
|---|---|---|
| **Mean** | 2.609091 | 0.902273 |
| Variance | 0.115113 | 0.01778 |
| Observations | 22 | 22 |
| **Pooled Variance** | 0.066447 | |
| **Hypothesized Mean Difference** | 0 | |
| df | 42 | |
| t Stat | 21.96071 | |
| P(T<=t) one-tail | 6.05E-25 | |
| t Critical one-tail | 1.681952 | |
| P(T<=t) two-tail | 1.21E-24 | |
| t Critical two-tail | 2.018082 | |

Since t Stat > 2.0181, therefore reject Ho=0, and conclude that there is significant difference between colour at sampling point V1 and sampling point v6 at 5% level of significance.